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Monitoring system for the consumption of electric energy in a household

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MONITORING SYSTEM FOR THE CONSUMPTION OF ELECTRIC ENERGY IN A HOUSEHOLD

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LA SALLE UNIVERSITY

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Acceptance Note

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Bogota, D.C.

DEDICATION

To God

Who guides my path and my days

Who gave me the strength and knowledge to fulfill this dream

To mom and dad

Who are always by my side

Who have helped me and supported on every situation and plan

To my family

To each of them

Who lent a hand when needed

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To all my professors that were part of my growth as engineer and person as well during all this time.

To my friends, who turned hard situations into funny moments and we all together grew up and worked out different situations, academic and life stuff.

To the laboratory crew, who were sometimes available to supply any equipment for us so we could achieve the goals in every single subject.

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GLOSSARY

CSS: *Cascading Style Sheets*, it is a style sheet language used to define the presentation of written documents in a markup language, such as HTML or XML. Its principal advantage is the separation between the format and the content of a document. Instead of setting the format within the document, the developer creates a link to a page that contains the styles, proceeding into an identical form to the rest of the pages of a web portal. When it is required to modify the appearance of the portal, it is just necessary to modify one simple file. (W3 Schools, 2015)

C++: it is a compiled programming language that lets the programming under several paradigms like procedural, object-oriented and generic programming. The C++ language belongs to no one, so it can be used without any kind of authorization or obligation to pay for author rights. C++ is one of the most popular programming languages with a large variation of material platforms and exploitation systems. (cplusplus.com, 2015)

DOMOTICS: the technology applied to home. Practically, it is to take automation, bring it out from the industrial processes and put it into a house. All of this in order to improve the security and comfort, and something more important so far: to save money from consumption costs.

ELECTRIC CONSUMPTION: the electric consumption of a device that consumes electricity to operate is given by the amount of electric power in a specific time. It is usually expressed in kilowatts consumed per hour (kWh). (RapidTables, 2015)

HTML: Hyper Text Markup Language, typical language to create web pages. (Study, 2015)

JAVASCRIPT: JavaScript is a script programming language mainly used in interactive webpages but also in servers as well. It is an object-oriented language, that is, the language bases and their principal interfaces are provided by objects that are not class instances, but constructive ones that allow creating their own properties, and specially a property that permits to recreate personalized hereditary objects. (W3 Schools, 2015)

KWH: kilowatt hour, it is the unit of energy equivalent to one kilowatt of power for one hour. The electrical energy consumed by households and equipment is related to this unit. (RapidTables, 2015)

MONITORING: it is the process that collects, analyzes, and uses specific information to follow up its progress to accomplish a particular objective.

MYSQL: related database management system. It is distributed under a double license: GPL and proprietary agreements. It is one of the most used database management application in the world, with web applications principally and professionally supported with Oracle, Informix and Microsoft SQL Server. (MySQL, 2015)

PHP: Hypertext PreProcessor, it is a free programming language, principally used to produce dynamic webpages through a HTTP server, but being also useful as any local interpretation language. PHP is an object-oriented imperative language, such as C++. (The PHP Group, 2015)

SERVER: Centralized computation system that offers some services to a network of computers. The computers that access to the services of the server are called *clients*, while the networks that use servers are *client-server* type. They respond automatically to the requests from the clients, and their formats are normalized, conforming to the network protocols. (TechTarget, 2015)

WEBPAGE: document, usually written in HTML, which contains media such as sounds, images, videos and text that allows the user to navigate the web, displaying on a monitor or mobile devices.

WI-FI: It is the normalization of a wireless network system for interconnecting several computers from different manufacturers. Because each manufacturer had the need to communicate its computers, they created their own networks, preventing the connection among different manufacturers. The unique solution was to create a wireless network, one in common for all the manufacturers, so the IEEE normalized it as 802.11b, or usually known as Wi-Fi.

ABSTRACT

Nowadays, an extra consumption of electric energy in the Colombian houses is generated due to electric or electronic elements plugged into the electric network. This fact produces a cost overrun in the user's electricity bills. To reduce this extra costs, and also with a plus of reducing greenhouse gas emission, a monitoring system for the consumption of electric energy in a household will be designed and implemented to make electricity users realize how much money and energy is being wasted due to the unnecessary electric elements plugged into the network.

In this project, a monitoring system is designed and tested, that allows the client to supervise the consumption of some appliances inside his home, remotely. It is also considered the HMI to be able to log in, choose the intervals of data and generate reports and graphics.

The monitoring system is based on the integration of several technologies that are already used and implemented at houses and buildings, such as:

- Measuring and treatment of data electronically using microcontrollers
- Wi-Fi technology
- Dynamic graphic interface (website)

INTRODUCTION

In the last two decades, the implementation of solutions for several issues in houses and buildings has become relevant for energy, security and comfort companies. The emergence of the words domotics (home automation) and inmotics (building automation) includes four essential aspects that definitely need to be solved: energy savings, convenience, safety and fun. Bringing security to a place, from cameras to automatic lockers in doors provides safeguarding and confidence to the user's property, while fun and convenience allow to enjoy every space and item easily. But saving energy has become the main and the most important subject to handle and to improve. (Smart Home, 2015)

In 2010, according to the World Bank, Colombia emitted 75,679.5 thousands of metric tons of carbon dioxide, only by fossil fuel burning, and 13.9 millions of metric tons due to electricity and heat production. (The World Bank, 2014)
The usage of electric and electronic devices, while plugged into the electrical network, besides generating certain amount of greenhouse gases, consumes kilowatts during the time they are plugged in. In an accidental or deliberated way, in the houses around the globe exist a waste of electric energy due to the misusing of the elements that require electricity to work, like appliances or the residential illumination. (The World Bank, 2014)

With the construction of the prototype sensors and the monitoring system, it is intended to show the need and the advantages that brings to the houses, so the client can realize and visualize the behavior of some of his appliances, with the final purpose of reduce the energy consumption of his house, the price of the bill and the emissions of carbon dioxide.

1 RELATED WORKS

At La Salle University, several topics have been developed by students and teachers, meeting wireless communication and remote control for automating processes or environments. In the particular case of domotics, the degree work **"DESIGN OF A HOME AUTOMATION SYSTEM FOR THE MANAGEMENT OF THE COMFORT IN A LIVING ROOM OF AN APARTMENT"** (Martínez Rodríguez & Moreno Vivas, 2010) presented a design of an automatic system for controlling the temperature conditions and electric elements that are in an apartment's living room. The wireless connection was implemented through a RALINK 3390 Wi-Fi card and the HMI using LabView software.

The previous work did not contemplate the control of the process in a personal way, as the engineers Santos and Aguirre did in **"DESIGN AND MODELING OF A SYSTEM FOR THE DOMOTIC CONTROL USING A MOBILE PHONE VIA BLUETOOTH, WAP AND TEXT MESSAGES".** In this project, a good solution is contemplated for achieving a better home automation control that could be executed in a mobile phone, such as WAP, ZigBee, X-10, Wi-Fi, and Bluetooth or via SMS. Then, the information system is designed to be able to control a shutter, lights and a smoke signal. (Santos Rozo & Aguirre Luna, 2009)

In 2013, the research in the domotics field continued with the degree work **"DESIGN AND IMPLEMENTATION OF A SYSTEM FOR MONITORING AND CONTROLLING ELECTRIC ENERGY CONSUMPTION NODES, USING MOBILE DEVICES AND BLUETOOTH TECHNOLOGY"** (Cruz, 2013), besides being the most recent project, contains a part of the proposal presented in this draft. This project consists of a software implementation developed in Netbeans and Java for the visualization and control of some electric elements (light bulbs, fan, electric lock, alarm, etc.) through a remote control via Bluetooth, implementing administrator and user validation for accessing the software from a mobile phone.

It is also appreciated and related the implementation of an electric tension sensor in the work **"IMPLEMENTATION OF A SMART SENSORS NETWORK USING WIRELESS COMMUNICATION, TO REDUCE THE ENERGY CONSUMPTION"** (Patiño López & Medellín Guzmán, 2014), which consists in the utilization of the solar energy using panels to recharge its own system's power supplies and regulate the energy supply to the sensors to make the data transmission, remotely, even more autonomous and efficient. The information to remark about this degree work is the type of sensor that was implemented for monitoring the consumption of electric energy.

Continuing with the degree works, now focused in monitoring with **"MONITORING SYSTEM AND DATA ACQUISITION FOR A CHEMICAL FERTILIZER DISTRIBUTION VEHICULE"**, where a group of subsystems are designed and started up, with the objective of transmit data information through wireless devices for it to be acquired, monitored and stored in a database. The data transmission was accomplished using a communication protocol module called ZigBee. (Martínez Peralta, 2013)

In 2010, the paper "**TINYEARS: SPYING ON HOUSE APPLIANCES WITH AUDIO SENSOR NODES"** carried out at the State University of New York, discusses the performance of a system called TinyEARS (Tiny Energy Accounting and Reporting System). Motivated by reducing costs, energy consumption, and impact on the environment, the TinyEARS is developed to detect and classify several turned on appliances using their own acoustic signatures to make reports of energy consumption. So, the sensor node is deployed in a room and it listens to the appliance, to know which one is on and accounts the time, to finally be able to calculate the energy consumed. The results show that the estimate working time of the monitored house appliances based on this correlation and their real working time reports less than a 10% error margin. (Z. Cihan, M. Amac, & Melodia, 2010)
In the Table 1, a summary of the related works is presented to appreciate the difference between the technology used and the application.

Table 1. Summary of related works

Author	Technology	Application
(Martínez Rodríguez & Moreno Vivas, 2010)	Wi-Fi	Control of temperature and electric elements
(Santos Rozo & Aguirre Luna, 2009)	GSM, Bluetooth and WAP	Home automation control
(Cruz, 2013)	Bluetooth	Control of electric elements
(Patiño López & Medellín Guzmán, 2014)	Bluetooth	Monitoring of autonomous solar panels
(Martínez Peralta, 2013)	Zigbee	Monitoring and acquisition of data
(Z. Cihan, M. Amac, & Melodia, 2010)	Acoustic sensors	Behavior of appliances in a house
Source: The author		

Different entities ensure that the energy consumption, in urban and rural sectors, have increased in the last three decades.

First, the Colombia's Ministry of Mines and Energy states the possible sources where energy can be obtained from, and the sectors they have been used. Since 1975 in the Colombian houses, different kinds of energy have been obtained from natural gas, mineral coal, firewood, LPG (liquefied petroleum gas), gasoline, kerosene, electric energy and charcoal.
In this three decades it can be seen an approximate increase of 11% of energetic consumption in the Colombian residences (from 44.600 Tcal in 1975 to 49.624 Tcal in 2006), where there was an increment in the use of energies such as natural gas and electricity in the urban residences, while gasoline and kerosene energies decreased in their participation. On the rural side, there was a general decrease of energetic consumption where its principal energy source, firewood, reduces its participation in half, but keeps on being the principal energetic, and where the electricity starts growing as a new option for these rural sectors. (Ministry of Mines and Energy, 2007)

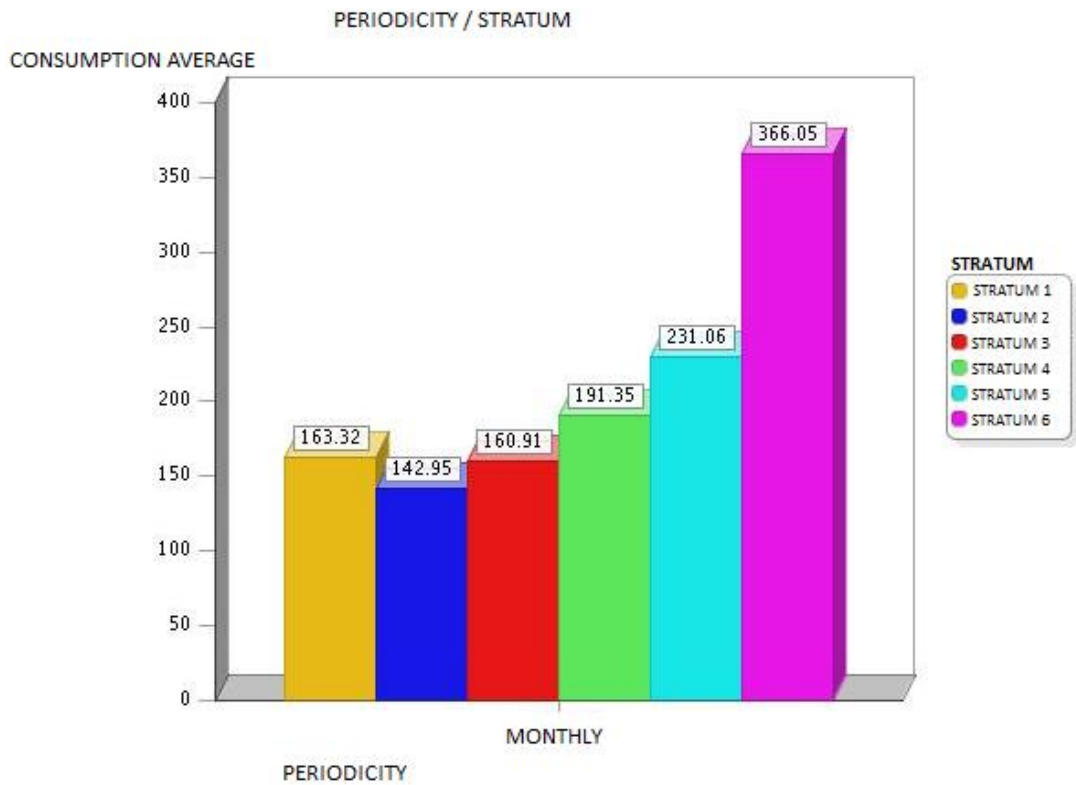
Taking the total of urban and rural Colombian residences, natural gas had the highest growth with an average annual rate of 27%, followed very far away by electricity with a 4,7%. This huge growth places natural gas on the top as the second energy with more consumption in the urban sector and the third in the rural one, while electricity holds the first position in urban residences and shares the top in the rural residences with the firewood. (Ministry of Mines and Energy, 2007)

Laying aside the residential perspective, and now from a purely point of view of the electric energy by person, i.e. per capita, the ECLAC submits a document about the amount of kilowatts per hour consumed by a habitant in a year, where the growth can be observed from 1970 to 2006. In 2006, the average of kilowatts per hour consumed by a Latin-American and Caribbean citizen was 1,688.1kWh, being the Chilean citizen the one with the highest consumption of electricity with 3,081.3kWh, and the Haitian with the barely consumption of 36kWh, the lowest one in the region. The Colombian citizen average is in the lower consumption table with 892.5kWh, proving that, in comparison with the rest of Latin-American and Caribbean citizens, consumes less electricity than most of the other Latin countries, and its consumption is below the average, (ECLAC, 2008) no matter the demand.

In Colombia, there is a remarkable social stratification, with the main function of classify people according to wealth and economic levels, starting from stratum 1, the lowest, to the highest, the stratum 6. These can be seen in public services, education and public health. By law, the higher stratums (4, 5 and 6) must subsidy the other lower stratums.

In the Figure 1, the monthly consumption of energy by stratums in 2014 can be appreciated. The consumption of the higher stratums is higher than the lower ones, being the stratum 6 with the highest rate of kilowatts per hour consumed. (Sistema Único de Información de Servicios Públicos, 2015)

Figure 1. Average consumption according to stratums in Colombia in 2014



Source: (Sistema Único de Información de Servicios Públicos, 2015)

2 OBJECTIVES

2.1 GENERAL OBJECTIVE

Implement a monitoring system for the consumption of electric energy in a household.

2.2 SPECIFIC OBJECTIVES

- Determinate the nodes of electric consumption and electric and/or electronic devices that are involved in the system.
- Select the sensor for the measuring of the consumption of electric energy.
- Design or select the power module of the system.
- Design the information system for monitoring the consumption of electric energy.
- Design the HMI for the monitoring system.
- Test the monitoring system in real-time.

3 THEORETICAL FRAMEWORK

In this chapter, a review of concepts, design tools, technical description of electronic elements, and softwares are presented to stand out their importance in the researching, developing, construction and testing of the monitoring system, stage by stage. Initially, a brief information of the tariff component and formula to obtain the kWh value, the consumption of some appliances is posted, also the selected sensor is presented and so is its physical phenomenon. Next, the microcontroller and Wi-Fi module are explained with the protocol communication. Later, the concepts of database, server and tools to develop them are listed and explained.

3.1 ELECTRIC ENERGY CONSUMPTION IN CONTEXT

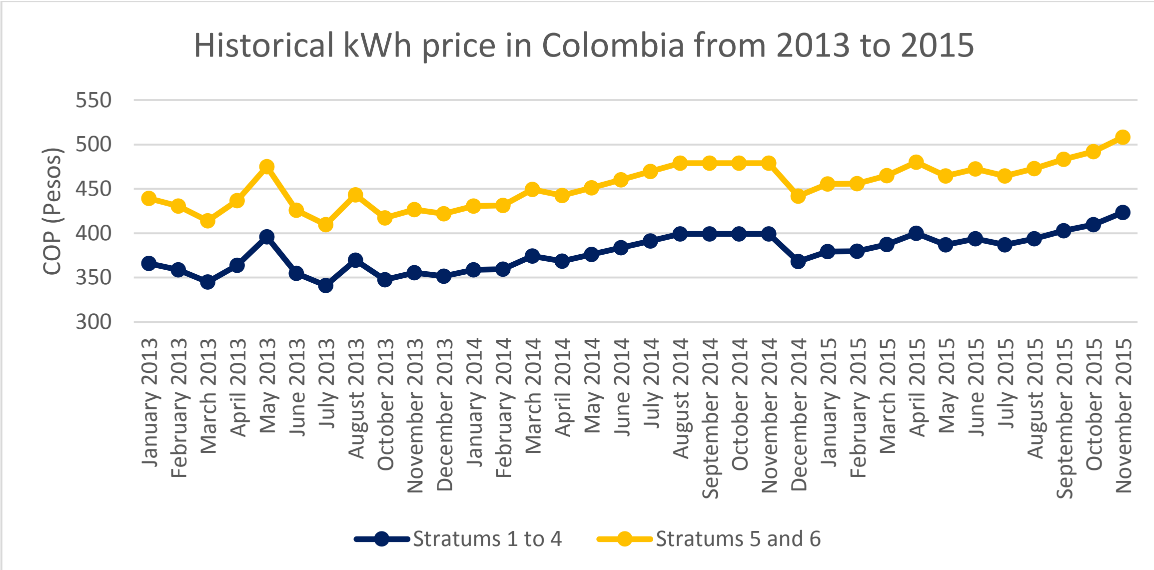
For the energy public service, each energy provider establishes the value for kilowatt hour, determined by the tariff formula established by the CREG, in the resolution 119 of December, 2007. (CODENSA, 2015) This formula contains six different items, listed below:

- G: energy purchase cost ($/kWh), determined based in the energy purchase costs of the immediately preceding month
- T: cost for the use of the national transmission system ($/kWh)
- D: cost for the use of the distribution system ($/kWh) corresponding to the tension level for the month
- CV: margin of marketing corresponding to the month ($/kWh)
- PR: cost of purchase, transportation and reduction of energy losses ($/kWh)
- R: cost of restrictions and associated services ($/kWh) with generation

In addition, the owners of commercial or industrial businesses must pay a 20% extra of their own energy consumption to subsidy the 3 lower stratums, according to Law 142 from 1994. (Secretaría General de la Alcaldía de Bogotá, 1994)

In the Figure 2, the historical of the kilowatt per hour price of every month since 2013 for every stratum is depicted, showing a progressive increase in 2015 due to El Niño’s phenomenon.

Figure 2. Price of kilowatt per hour in Colombia from 2013



Source: Codensa

To understand and to know the charge of the electricity bill, it is mandatory to know what appliances are connected to the electric network and how much kilowatts they consume and how much time they are plugged. In the Table 2, a summary lists the most common appliances at home with important information such as number of appliances in a default house, active usage, standby wattage and total kWh consumed per year. (Home Energy Saver, 2015)

Table 2. Default energy consumption of appliances

Appliance	Number present in default house	Active usage (hours/years)	Standby Wattage	Total kWh
CD Player	1	26	3.7	19
DVD Player	0	208	5.5	17
Receiver	1	104	2.8	27
TV (CRT)	2	730	6.4	216
TV (LCD)	0	730	6.4	179
TV (Plasma)	0	730	6.4	161
CPU	1	1825	1.2	132
Home copier	0	183	5.1	190
Laptop charger	0	0	4.5	39
Monitor	1	1825	2	167
Printer (Laser)	0	52	4.2	50
Router	1	1825	2	25
Coffee maker: drip	1	183	1	282
Coffee maker	0	183	0	110

Table 2. Default energy consumption of appliances (Continuation)

Microwave	1	79	2.8	103
Slow cooker	0	693	0	139
Toaster	0	140	0	210
Aquarium	0	8760	0	548
Clock	2	0	1	9
Doorbell	1	0	5	44
Hair dryer	1	49	0	35
Iron	0	48	0	53
Source: (Home Energy Saver, 2015)				

3.2 HALL EFFECT-BASED LINEAR CURRENT SENSOR ACS712

The selected sensor for measuring AC current is the ACS712. This is a Hall Effect current sensor manufactured by Allegro™ that generates a magnetic field when a current flows through a copper conductor, and it is converted into a proportional voltage. It is chosen because it has several advantages such as price, compatibility, versatility, lineal response, etc. In the other hand, there are two important disadvantages: it is an invasive sensor, i.e. it is necessary to open the circuit or in this case one of the lines to be able to measure the flowing current, and it is not useful to measure lower currents, such as micro and milliamps.

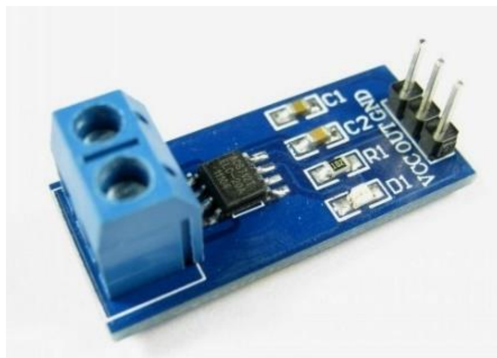
There are three different versions of the sensor, depending of the current range: up to 5, 20 and 30A. This fact helps to use the proper range sensor to measure any appliance, just knowing the current consumed.
It is important to know and to choose the proper range sensor to get more accurate data and take a full advantage of the ADC conversion later on. The sensor can be appreciated in the Figure 3. (Allegro, 2012)

More technical information:

- Low-noise analog signal path
- Device bandwidth is set via the new FILTER pin
- 5 μs output rise time in response to step input current
- 80 kHz bandwidth
- Total output error 1.5% at TA = 25°C
- Small footprint, low-profile SOIC8 package
- 1.2 mΩ internal conductor resistance
- 2.1 kVRMS minimum isolation voltage from pins 1-4 to pins 5-8
- 5.0 V, single supply operation

- 66 to 185 mV/A output sensitivity
- Output voltage proportional to AC or DC currents
- Factory-trimmed for accuracy
- Extremely stable output offset voltage
- Nearly zero magnetic hysteresis
- Ratiometric output from supply voltage

Figure 3. Hall effect-based linear current sensor ACS712



Source: (Geek Factory, 2015)

The device consists of a precise, low-offset, linear Hall circuit with a copper conduction path located near the surface of the die. Applied current flowing through this copper conduction path generates a magnetic field which the Hall IC converts into a proportional voltage. Device accuracy is optimized through the close proximity of the magnetic signal to the Hall transducer. (Allegro, 2012)

The main criteria for choosing this sensor is the availability in the market to get it. Also, it was required to be a tiny sensor, not like the SCT-013-000 which is clamp-shaped, due that it is intended to be encapsulated and it is pretty cheap. The linear response and versatility of having three different and specified operation ranges (5, 20 and 30A) helped with the election of the sensor.

3.3 ARDUINO

Arduino is an open-source prototyping platform based on easy hardware and software. This platform has developed lots of different Arduino boards, and they are used and selected according to the function they are required. These boards use microcontrollers that need to be bootloaded to be programmed. Arduino is based on C and C++ language, and has its own software called Arduino Software IDE that runs on Windows, Mac OS X and Linux. Its environment is written in Java.

It was especially designed for small and educational projects. The boards are adapted to every single pin of the microcontroller, so the user can plug any wire as he wishes. It counts with its own power supply and allows to use 5 and 3,3V to supply any other circuit. In the Figure 4, the Arduino board is presented. (Arduino, 2015)

Figure 4. Arduino UNO and Genuino UNO board

Source: (Arduino, 2015)

3.4 WI-FI TECHNOLOGY

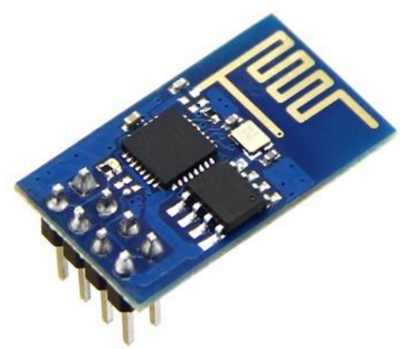
Abbreviation of *Wireless Fideliy,* it is the normalization of a wireless network system for interconnecting several computers from different manufacturers. Because each manufacturer had the need to communicate its computers, they created their own networks, preventing the connection among different manufacturers. The unique solution was to create a wireless network, one in common for all the manufacturers, so the IEEE normalized it as 802.11b, or usually known as Wi-Fi. (Carballar, 2004)

3.5 ESP8266 802.11BGN SMART DEVICE

The ESP8266 is a low power Wi-Fi module pretty cheap which is mostly used in the "Internet of Things", and it is able to communicate via serial with microcontrollers. It is used to send HTTP request, create webservers, toggle pins, etc. Its technical specifications are listed below, while it can be seen in the Figure 5. (Espressif Systems, 2013)

- 802.11 b/g/n protocol
- Wi-Fi Direct (P2P), soft-AP
- Integrated TCP/IP protocol stack
- Integrated TR switch, balun, LNA, power amplifier and matching network
- Integrated PLL, regulators, and power management units
- +19.5dBm output power in 802.11b mode
- Integrated temperature sensor
- Supports antenna diversity
- Power down leakage current of < 10uA
- Integrated low power 32-bit CPU could be used as application processor
- SDIO 2.0, SPI, UART
- STBC, 1×1 MIMO, 2×1 MIMO
- A-MPDU & A-MSDU aggregation & 0.4μs guard interval
- Wake up and transmit packets in < 2ms
- Standby power consumption of < 1.0mW (DTIM3)

Figure 5. ESP8266 802.11BGN smart device



Source: (Seeed, 2015)

It also counts with an internal processing unit which is also programmable, and two general purpose input output pins. It operates at 3,3V. This module communicates with the microcontroller via serial through AT commands, to configure and perform several instructions. In the Table 3, the detailed AT commands are listed, the ones which were used to run the ESP8266. (Pridopia)

Table 3. AT commands for the ESP8266 communication

AT Command	**Function**	**Syntax**	**Description**
AT	General test	AT	Responses OK if it is working
AT+RST	Restart	AT+RST	Responses OK when finished
AT+CWMODE	Wi-Fi mode	AT+CWMODE=<X>	If X: 1=Station, 2=AP, 3=Both
AT+CWLAP	List access points	AT+CWLAP?	Shows the available access points
AT+CWJAP	Join access point	AT+CWJAP=<"user">, <"pass">	user= network username pass= network pass
AT+CIFSR	Get IP address	AT+CIFSR	Responses with IP if connected
AT+CIPMUX	Set type of connection	AT+CIPMUX=<X>	If X: 1=single, 2=multiple
AT+CIOBAUD	Get baud rate	AT+CIOBAUD? AT+CIOBAUD=<X>	If X: 9600, 19200, 38400, 74880, 115200, 230400, 460800 and 921600.
AT+CIPSTART	Open TCP/UDP connection	AT+CIPSTART=<id>, <X>,<http>,<port>	id 1-4; if X: TCP or UDP; http=php file path
AT+CIPSEND	Send TCP/IP data	AT+CIPSEND=<id>, <length>	id 1-4; data length
AT+CIPCLOSE	Close TCP/UDP connection	AT+CIPCLOSE=<id>	id 1-4
Source: (Pridopia)			

3.6 INFORMATION SYSTEM

An information system represents the gathering of the elements that participate in the management, treatment, transport and diffusion of the information in the center of the organization. Concretely, the term *information system* can be very different from an organization to another and can be interpreted according to: (Comment Ça Marche, 2015)

- Database of the company,
- Enterprise Resource Planning,
- Customer Relation Management
- Supply Chain Management
- Application methods

- Infrastructure network
- Data servers and storage systems
- Application servers
- Security devices

3.6.1 Database: A database is a collection of related data, a group of facts that can be stored and have an implicit meaning. The databases represent aspects of the real world, and are designed, created and filled with data with a specific purpose, and they are distinguished by the coherence of the data that remains within themselves (Elmasri & Navathe, 2002). Below, some specific applications of databases:

- Banking: information of clients, accounts, leasing and banking transactions.
- Airlines: schedules, booking. The flight companies were the first to use databases in a geography distributed form.
- Universities: student information, registration.
- Credit card transactions: When buying using a credit card and the generation of the monthly statements.
- Telecommunications: to store the logs, generate the monthly billing, to keep prepay telephonic cards balances and any other information about the communication networks.
- Finances: to store information about companies, sales and purchases of financial products, such as shares. Also to store market data in real time to allow the clients the online trading and the company the automatic trading.
- Sales: client information, products and purchases.
- Online trading: for the data of sales already mentioned and for the monitoring of the Web orders, generation of lists of recommendations and maintaining of online product evaluations.
- Human resources: information about employees, salaries, taxes, social benefits and pay sheet generation.

3.6.2 Database Managing System: A database managing system is a collection of interrelated data and a group of programs to access to the information. The collection of data, that is the database, contains relevant information to an enterprise. Its main objective is to supply a way to store and recover the information within a database, making it simple and efficient. These systems are designed to manage large amounts of information. It implies an architectural structuration and mechanisms to manipulate the information as well. (Silberschatz, Korth, & Sudarshan, 2007)

3.6.3 Unified Modeling Language: The Unified Modeling Language (UML) is Object Management Group's most-used specification, and the way the world models not only application structure, behavior, and architecture, but also business process and data structure. It helps to specify, visualize, and document models of software systems, including their structure and design, in a way that meets all of these requirements. (It also can be used for business modeling and modeling of other non-software systems too.) Using any one of the large number of UML-based tools on the market, it is possible to analyze future application's requirements and design a solution that meets them.

It can model just about any type of application, running on any type and combination of hardware, operating system, programming language, and network, in UML. Its flexibility lets model distributed applications that use just about any middleware on the market. Built upon fundamental object-oriented concepts including class and operation, it's a natural fit for object-oriented languages and environments such as C++, Java, and the recent C#, but it can be used it to model non-object-oriented applications as well. (Object Management Group, 2015)

3.7 USE CASE DIAGRAMS

The use case diagrams present graphically the management, relation, and requirements between the user and the system. The elements that belong to these diagrams are:

- Use cases: describes a sequence of actions that provide something of measurable value to an actor and is drawn as a horizontal ellipse.
- Actors: a person, user, organization, or external system that plays a role in one or more interactions with your system. Actors are drawn as stick figures.
- Associations: associations between actors and use cases are indicated in use case diagrams by solid lines. An association exists whenever an actor is involved with an interaction described by a use case. Associations are modeled as lines connecting use cases and actors to one another, with an optional arrowhead on one end of the line. The arrowhead is often used to indicating the direction of the initial invocation of the relationship or to indicate the primary actor within the use case. The arrowheads are typically confused with data flow and as a result I avoid their use. (Ambler, 2014)

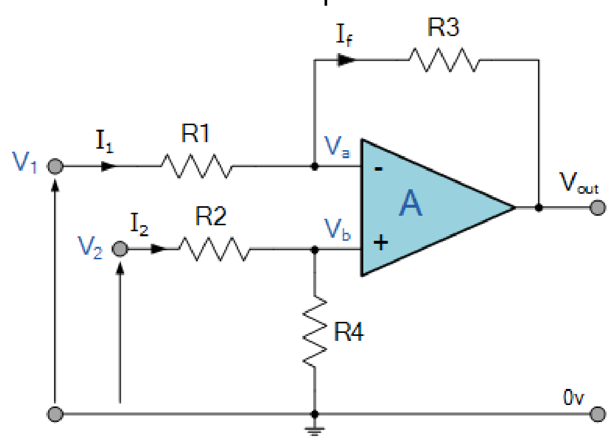
3.8 OPERATIONAL AMPLIFIERS

The operational amplifier (op amp), according to Arthur Williams, is probably the most popular block used in the design of electronic circuits, by doing as linear as nonlinear operations on electrical signals. The op amp is an amplifier of high gain with two input terminals (inverting and non-inverting), one output terminal and an intern and direct coupler. The output voltage is the difference between the voltages applied to each input terminal, multiplied by the gain of the amplifier. (Williams, 1988)

A positive signal applied to the positive input results into a positive change in the output, which is why this terminal is known as the non-inverting input. A positive signal applied to the negative input results into a negative change in the output, so that the negative input is known as the inverting one. (Williams, 1988)

3.8.1 Differential amplifier: The differential amplifiers amplifies the difference between two voltages, making a subtraction. Many circuits have just one input, while the other is grounded, but in this case where a sensor can have both terminals biased at 5VAC above ground, making it necessary to amplify the difference between these terminals and reject the bias. In the Figure 6, the schematic circuit of the differential amplifier is presented.

Figure 6. Schematic circuit of a differential amplifier



Source: (Basic Electronic Tutorials, 2015)

Also, if the input V_1 is higher than the input V_2, the output voltage will be negative, and if the input V_2 is higher than the input V_1, the output will become positive. (Basic Electronic Tutorials, 2015)

3.9 XAMPP

XAMPP is an open-source web server package that works on various platforms. It is actually an acronym with X meaning “cross” platform, A for Apache HTTP server, M for MySQL, P for PHP, and P for Perl. XAMPP was designed to help webpage developers, programmers, and designers check and review their work using their computers even without connection to the web or internet. Basically XAMPP may be used to stand as pages for the internet even without connection to it. It can also be used to create and configure with databases written in MySQL and/or SQLite. And since XAMPP is designed as a cross-platform server package, it is available for a variety of operating systems and platforms like Microsoft Windows, Mac OS X, Linux, and Solaris. (Erwin, 2011)

3.10 ADOBE DREAMWEAVER CC

Dreamweaver is a program basically made for website designing. It was developed by Adobe and allows the user to create, modify, edit, and manage webpages based on several programming languages such as PHP, HTML, JAVASCRIPT, Visual Basic, etc, starting from empty files or using previous templates. (Adobe, 2015)

4 METHODOLOGY

The methodology consists of several tasks, starting from documentation of the variables, instrumentation and methods for getting to the solution, the implementation of the different stages of the system, like the selection of the communication module, database, power stage, etc., being these tasks a derivation from the previous objectives. In the Figure 7, it can be observed the flow chart of the methodology.

4.1 ANALYSIS OF THE CONSUMPTION NODES

The first part of the methodology focuses on selecting the electric and/or electronic elements to be monitored, so the instrumentation to be able to monitoring.

- Environment study: The variables and consumption nodes to be treated are identified, so does the environment in general where the sensors are going to be placed, and the connections, etc.
- Sensors selection: According to the mentioned sensors in the background, a comparison is made among the different possibilities, having in mind the versatility, reliability, costs, functioning and robustness of the sensors.
- Sensing test: Verification and confirmation that the sensors, which have been placed in the elements to be measured, sense correctly.

4.2 POWER STAGE

In this stage the measured signals from the sensors while sensing the electric nodes are adjusted, so does the transmission and reception.

- Analysis of the signals from the sensors: The study of the characteristics of the signals sent by each sensor.
- Amplification and treatment of the signals: The treatment of the signals to the system to be able to interpret them.
- Transmission and reception of data: A study and an analysis are made about the different technologies to be implemented to fulfil the wireless transmission and reception of data.
- Design of the communication protocol: Design of the communication system for interpretation and manipulation of data.

4.3 INFORMATION SYSTEM

This is where the received data from the sensors is stored and managed, for further organization and visualization.

- Analysis of the model of use cases: Identification of actors and actions that are involved in the system.
- Server selection: Study of the different server to manage the database.
- Design of the database: The variables, tables, fields, profiles are determined for managing the information.
- Connection between sensors and database: Correct data transmission and managing to the database from the sensors.

4.4 HMI

Design of the graphic interface that allows the user to monitor the consumption of the electric energy.

- Selection of the programming tool: A software is chosen so it can be executed in the mobile devices that will run the program and/or application.
- Window characterization: Determinate the content and versatility of each window of the application.
- Design of the graphic environment: According to international norms, so the interface to be comfortable with the user (size, colors, letter type, etc.).

4.5 STARTING UP

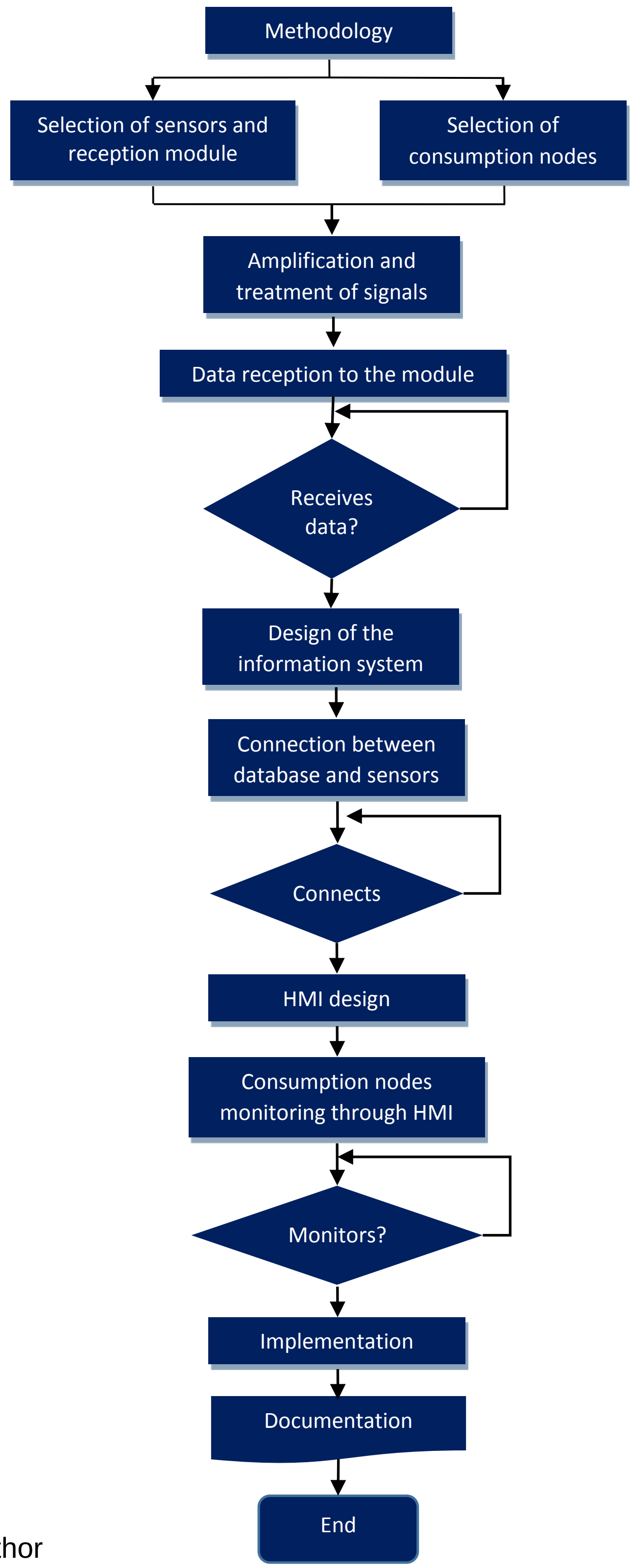
The complete integrated system is validated, where every stage is tested to prove their veracity, and determinate if the objectives meet.

4.6 DOCUMENTATION

The final document is redacted, along with the operation’s manual.

- Redaction of the operation’s manual: The manual is too important for any person who wants to acquire the monitoring system.
- Redaction of the final document: The final document must include all the process that has been through to get to the accomplishment of the objectives.

Figure 7. Flowchart of the methodology



Source: The author

5 ANALYSIS OF THE CONSUMPTION NODES

Several household elements used every day require some electric current to work properly. Some appliances were measured, five of these were chosen to analyze their behavior while they are connected and running, and the rest can be appreciated in the Appendixes A to H. The chosen appliances are detailed in the Table 4.

Table 4. Brief description of the chosen appliances

Household	Technical information	Implementation	Image
Washing machine	Mabe AC127V ±10% 60Hz 10,5A Model LCA18LE	Machine used to wash and clean clothes and sheets	
Refrigerator	ICASA AC115V 60HZ Model: de Ville	Appliance that keeps a constant temperature so food can be conserved inside it.	
Steam iron	Toastmaster AC120 60Hz 1100W Model 3302	Appliance used to remover creases from clothes while pressing it to them.	
LED TV	Samsung AC100-240V 60Hz, 100W Model UN32C4000P	Device allowed to display media such as TV programs, videos, images and sounds.	

Fluorescent lightbulb	Sylvania AC120-127V 50/60Hz 20W 286mA 6500K P.F 0.5 Max Temp 45° Model: Mini-Lynx Spiral	Component that produces light when connected, to enlighten places.	
Source: The author			

The following data were acquired using the circuits for the 5A and 20A ACS712 current sensor …see section 6.2… taken a sample every second.

5.1 WASHING MACHINE

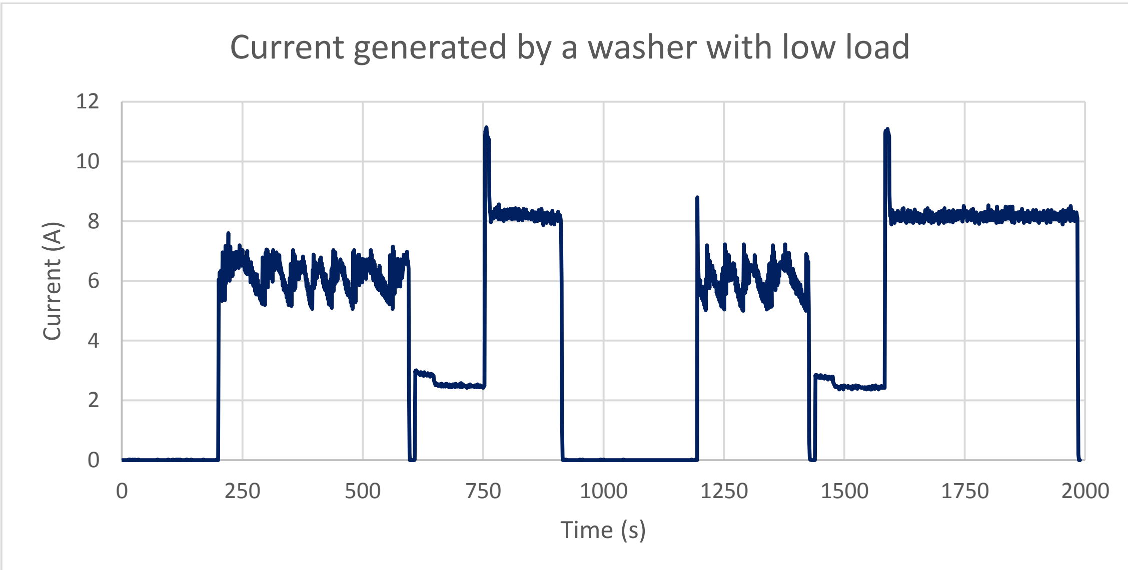
The washing machine chosen for measuring its behavior was manufactured by Mabe Centrales, model LCA18LE. It requires AC110V at 60Hz to work. It consists of 3 operation modes according to the load (low, medium or high) and its wash cycle goes through different stages:

1. Filling the drum: The drum is automatically filled with hot or cold water by opening a valve and its level depends on the operation mode selected previously. Also, soap must be added and the clothes as well.
2. Main centrifuging: The drum starts rotating during some period of time, which accords with the operation mode selected.
3. Standby: Short period of time after the main centrifuging is done.
4. Pumping water: The water used to do the main centrifuging is pumped out of the drum.
5. Spinning: The drum starts rotating at a high speed for the clothes to be dried.
6. Filling the drum: The drum is filled again to perform the second part of the wash cycle, with the purpose of prevent static cling and keep clothing smooth and with nice smell. The fabric softener must be added.
7. Second centrifuging: The drum rotates in a shorter time than the main one.
8. Standby: Another short period of time before pumping water.
9. Pumping water: The water is pumped out of the drum to do the spinning.
10. Final spinning: the drum rotates at high speed to dry the clothing. Finally, the clothes are clean, dry and ready to leave the washing machine.

This household was chosen because of its variable current while running.

5.1.1 Low capacity: The drum is filled to a low level. The cycle lasts approximately 1985 seconds, with a total energy consumed of 0.294kWh. In the Figure 8, it can be seen the behavior of the current versus time while the Figure 9 shows the rising of the consumed power.

Figure 8. Current generated by the washing machine with low load

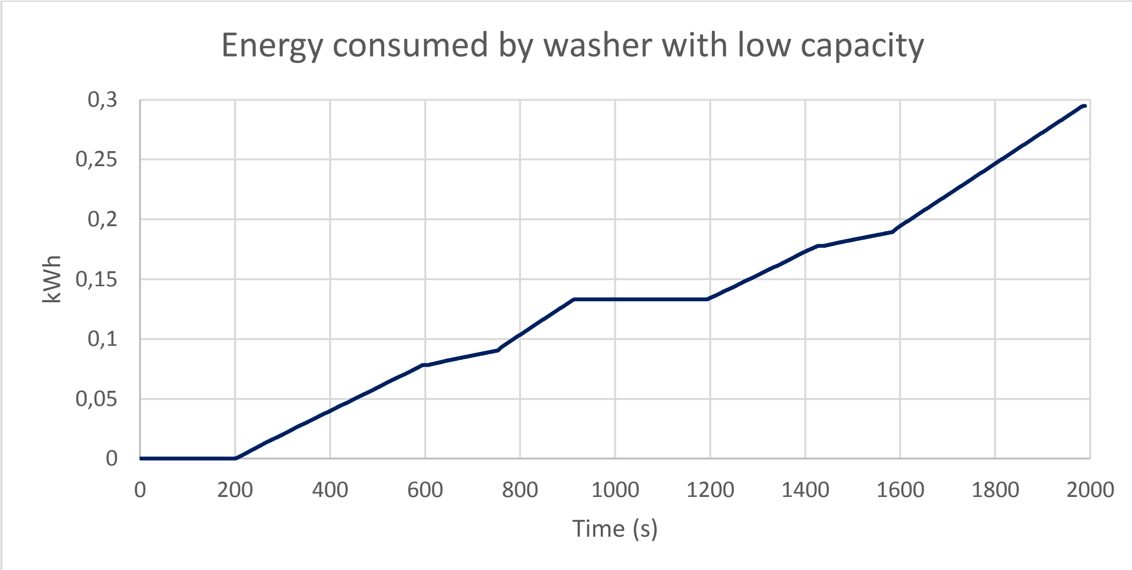


Source: The author

For each stage:

- Filling: 200 seconds, 25mA, 12.98Wh consumed.
- Main centrifuging: 397 seconds, current varies from 7.1A to 5A, 65.42Wh consumed.
- Standby: 11 seconds, no current and no energy consumed.
- Pumping: 145 seconds, currents starts in 3A and decreases to 2.4A, 12.04Wh consumed.
- Spinning: 162 seconds, current varies from 8.5A to 7.8A, 42.59Wh consumed.
- Filling: 279 seconds, 25mA, 6,9Wh consumed.
- Second centrifuging: 233 seconds, current varies from 7.2A to 4.9A, 44.69Wh consumed.
- Standby: 12 seconds, no current and no energy consumed.
- Pumping: 145 seconds, currents starts in 2.8A and decreases to 2.3A, 11.6Wh consumed.
- Spinning: 401 seconds, current varies from 8.3A to 7.8A, 105.31Wh consumed.

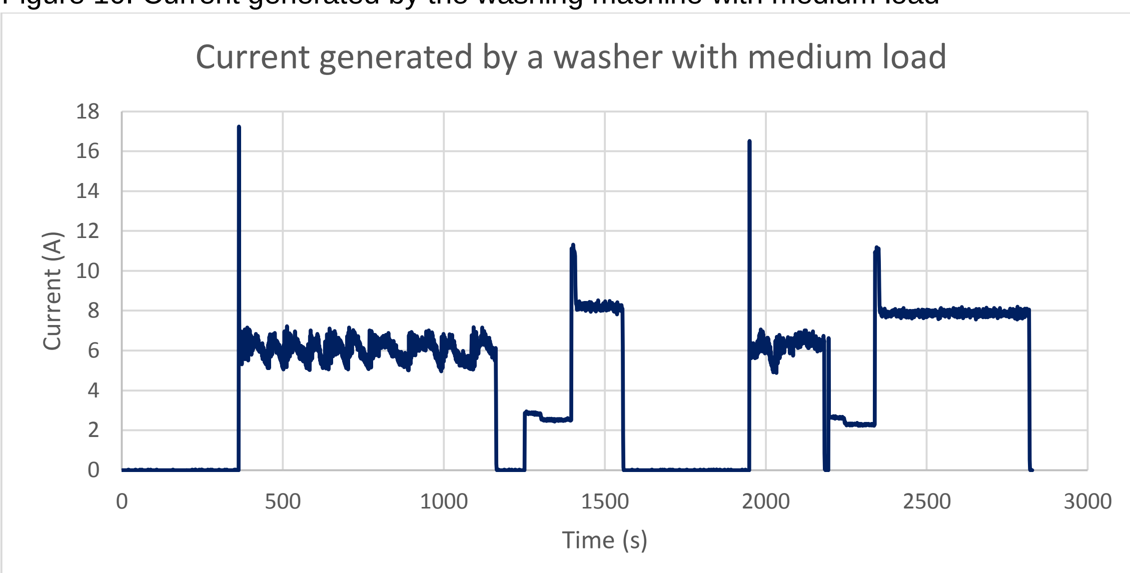
Figure 9. Energy consumed by the washing machine with low load



Source: The author

5.1.2 Medium capacity: The drum is filled to a medium level. The cycle lasts approximately 2821 seconds, with a total energy consumed of 0.39kWh. In the Figure 10, it can be seen the behavior of the current versus time while the Figure 11 shows the rising of the consumed power.

Figure 10. Current generated by the washing machine with medium load

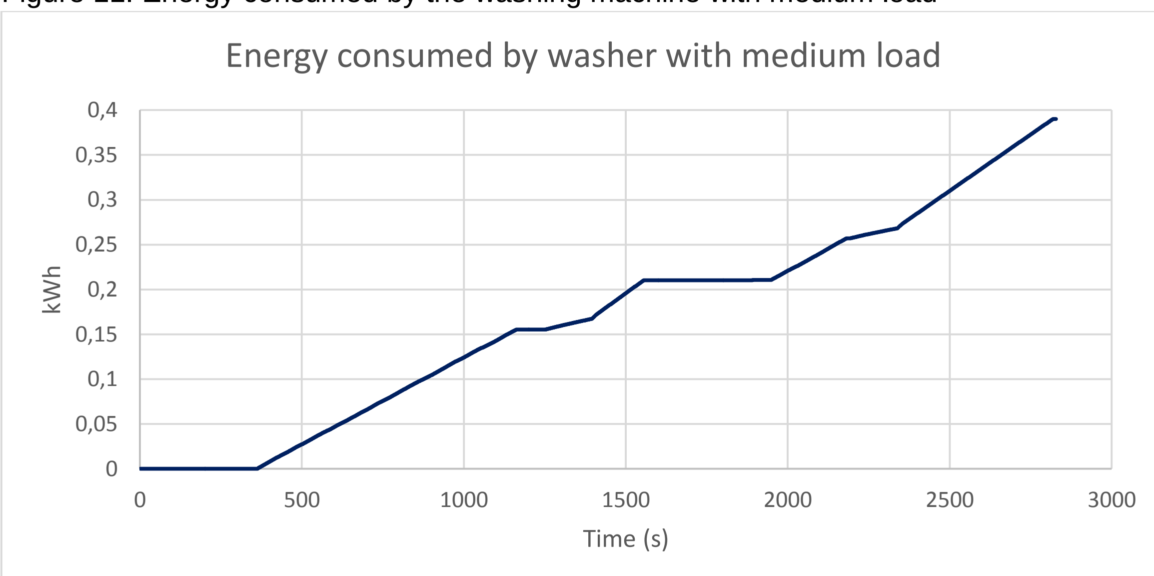


Source: The author

For each stage:

- Filling: 363 seconds, 25mA, 17.57Wh consumed.
- Main centrifuging: 799 seconds, current varies from 7A to 4.9A, 155.2Wh consumed.
- Standby: 89 seconds, no current and no energy consumed.
- Pumping: 145 seconds, currents starts in 2.8A and decreases to 2.4A, 12.41Wh consumed.
- Spinning: 161 seconds, current varies from 8.4A to 8A, 42.65Wh consumed.
- Filling: 432 seconds, 25mA, 0.29Wh consumed.
- Second centrifuging: 233 seconds, current varies from 7.1A to 4.9A, 46.047Wh consumed.
- Standby: 11 seconds, no current and no energy consumed.
- Pumping: 145 seconds, currents starts in 2.7A and decreases to 2.25A, 10.98Wh consumed.
- Spinning: 401 seconds, current varies from 8.2A to 7.55A, 121.43Wh consumed.

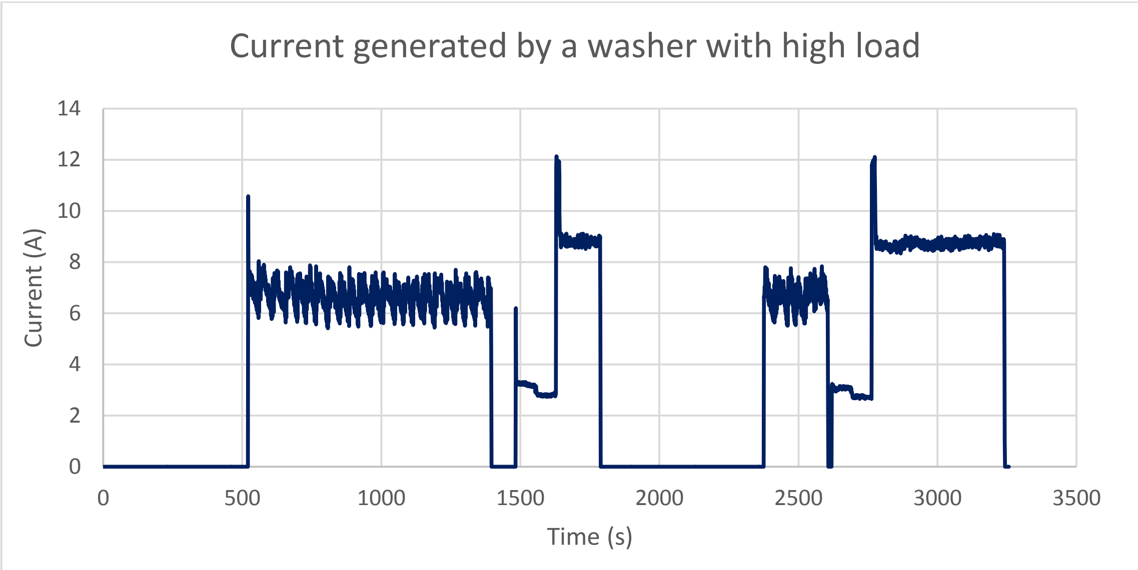
Figure 11. Energy consumed by the washing machine with medium load



Source: The author

5.1.3 High capacity: The drum is filled to a medium level. The cycle lasts approximately 2821 seconds, with a total energy consumed of 0.39kWh. In the Figure 12, it can be seen the behavior of the current in time while the Figure 13 shows the rising of the consumed power.

Figure 12. Current generated by the washing machine with high load

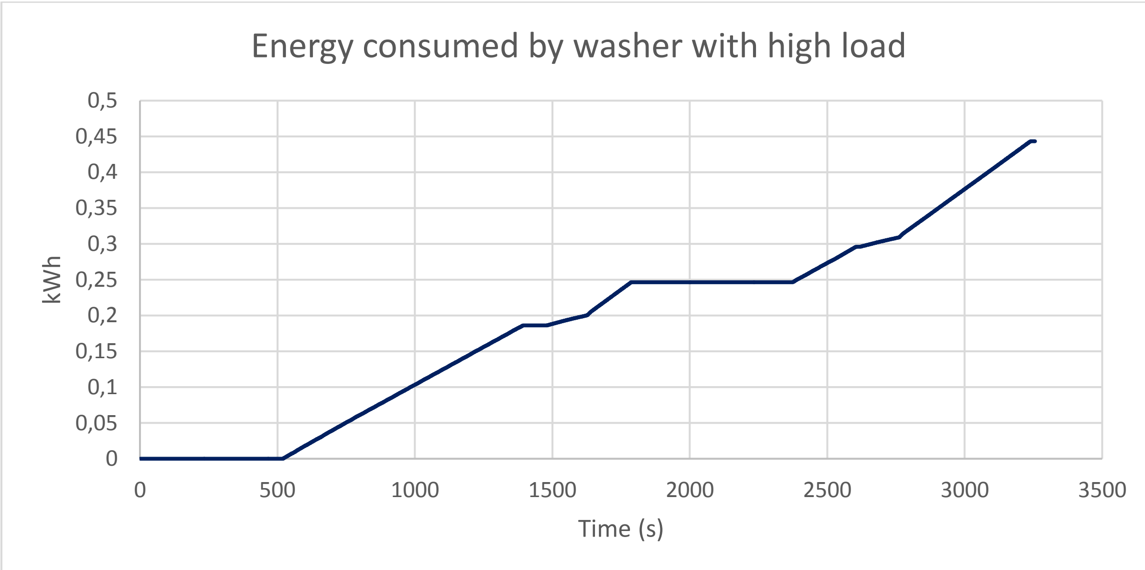


Source: The author

For each stage:

- Filling: 520 seconds, 25mA, 0.4Wh consumed.
- Main centrifuging: 875 seconds, current varies from 8A to 5.3A, 186Wh consumed.
- Standby: 88 seconds, no current and no energy consumed.
- Pumping: 145 seconds, currents starts in 3.3A and decreases to 2.75A, 14.75Wh consumed.
- Spinning: 160 seconds, current varies from 9.1A to 8.5A, 45.675Wh consumed.
- Filling: 587 seconds, 25mA, 0.22Wh consumed.
- Second centrifuging: 231 seconds, current varies from 7.8A to 5.5A, 49.14Wh consumed.
- Standby: 13 seconds, no current and no energy consumed.
- Pumping: 144 seconds, currents starts in 3.15A and decreases to 2.65A, 13.96Wh consumed.
- Spinning: 478 seconds, current varies from 8.2A to 7.55A, 123.69Wh consumed.

Figure 13. Energy consumed by the washing machine with high load

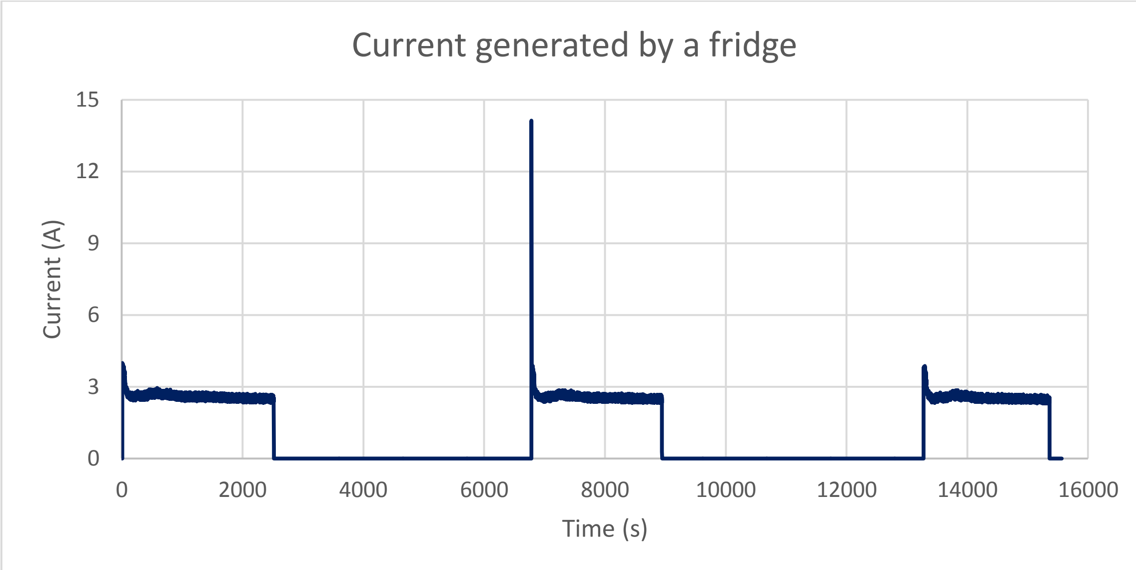


Source: The author

5.2 REFIGERATOR

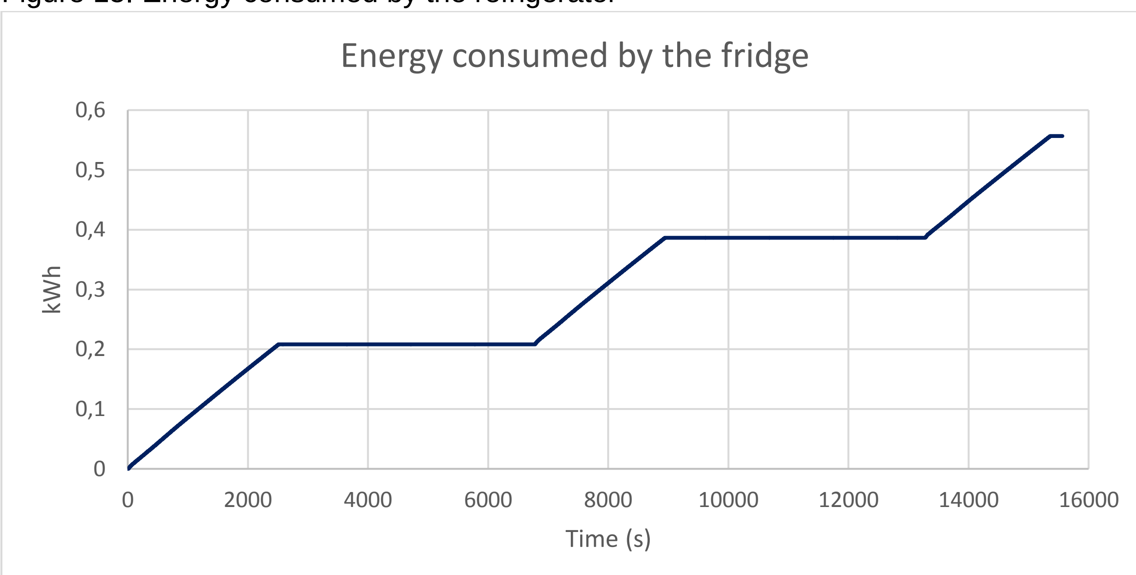
The refrigerator that was chosen for measuring its behavior was manufactured by ICASA, approximately 30 years ago, model *de Ville*. It requires AC110V at 60Hz to work. Due to its operation time since acquired, the plate is age-worn and its technical information is unable to be read. The Figure 14 shows the current generated by the refrigerator, starting around 3,7A and dropping below 2,7A with a starting current of 14A, while the Figure 15 presents the rising of the consumed power. According to the data, the refrigerator consumed 0,556kWh during 15564s. It can be seen in the Figure 14 that the refrigerator takes approximately 2254s to cool before it stops and 4300s to start over.

Figure 14. Current generated by refrigerator



Source: The author

Figure 15. Energy consumed by the refrigerator

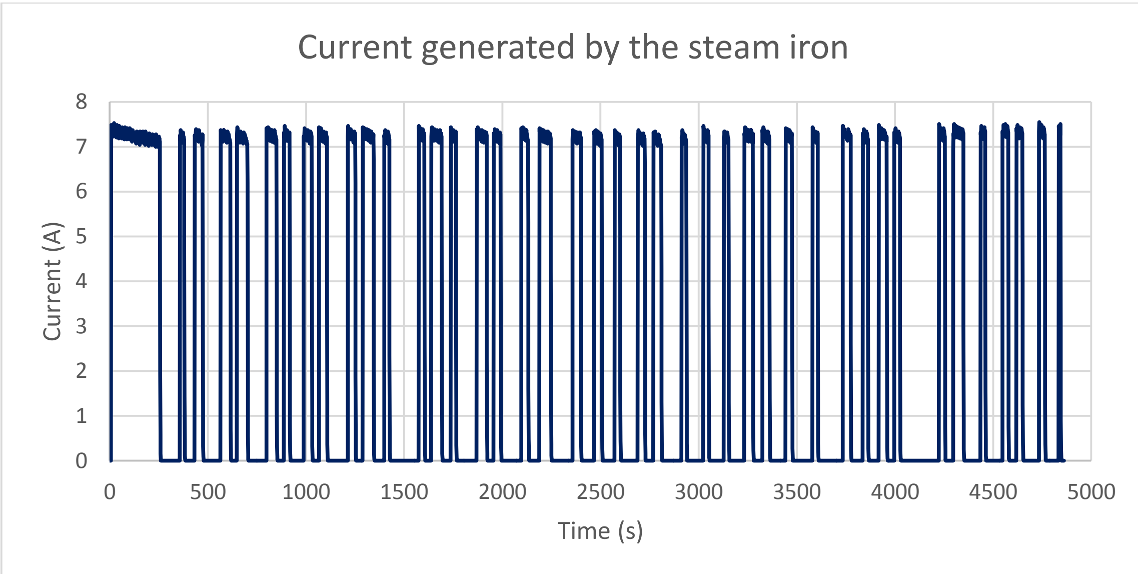


Source: The author

5.3 STEAM IRON

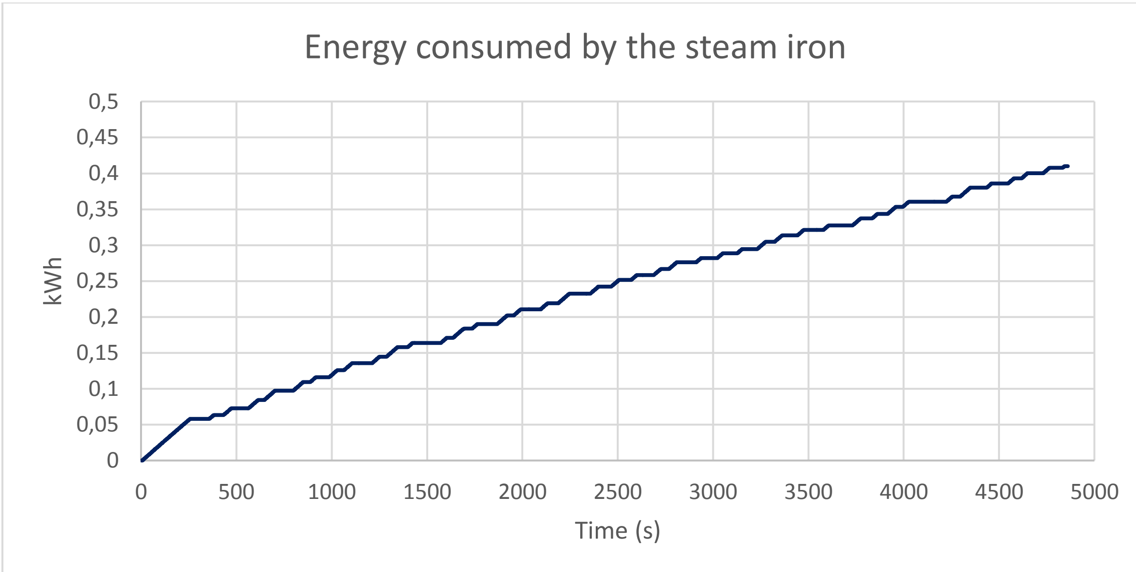
The steam iron chosen was manufactured by Toastmaster, model 3302, which requires AC110V at 60Hz to work. The steam iron was chosen to be measured because it is one of the appliances that consumes the most, and it is constantly changing from on to off. This appliance, when connected, starts generating up to 8A, and drops to 7A. The resistance starts heating up and when it reaches certain temperature, it stops consuming, to avoid overheating and damage to the iron. But when the temperature decreases, it reconnects itself to warm up again until the maximum temperatures is reached again. These times depends on how many time the iron is on the clothes. In the Figure 16, the current generated when the steam iron is used is graphed in time, while the energy consumed can be seen in Figure 17. According to the data collected, the steam iron consumed 0,41kWh during 4860s.

Figure 16. Current generated by the steam iron



Source: The author

Figure 17. Energy consumed by the steam iron



Source: The author

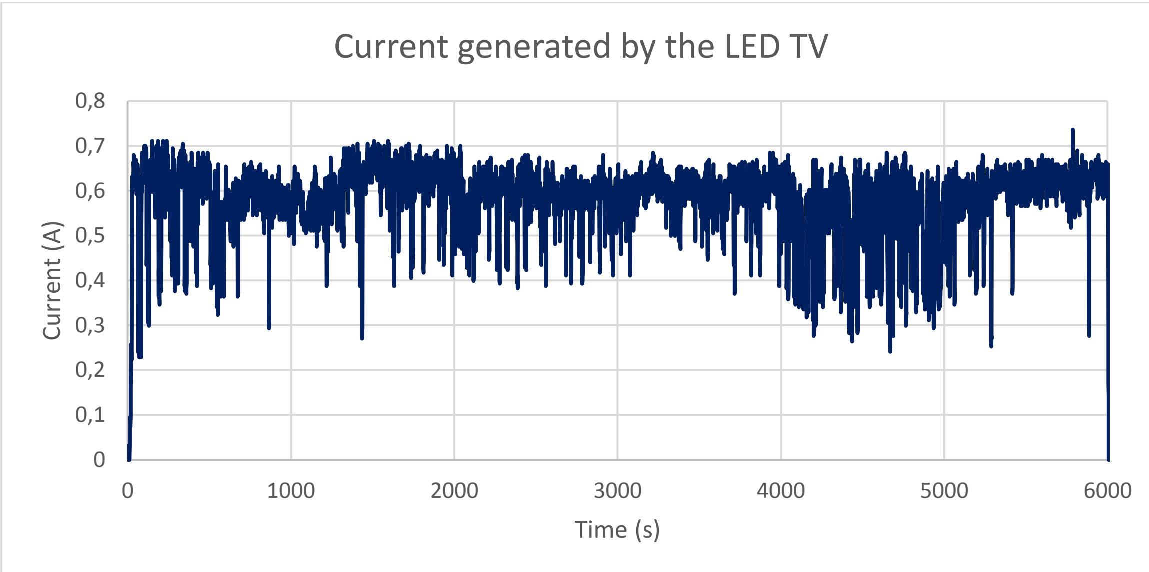
5.4 LED TV

The 32'' Samsung LED TV is a low-consuming appliance due to its LED technology. According to its technical label, it requires AC110 to 240V at 60Hz and consumes 100W. The consumption of this appliance depends on the images that it projects. The more illuminated, the higher consumption, so this LED TV has 3 picture modes, with different luminaire intensities and generation of current as well (approximations):

- Dynamic: 0.785A
- Standard: 0.65A
- Cinema: 0.485

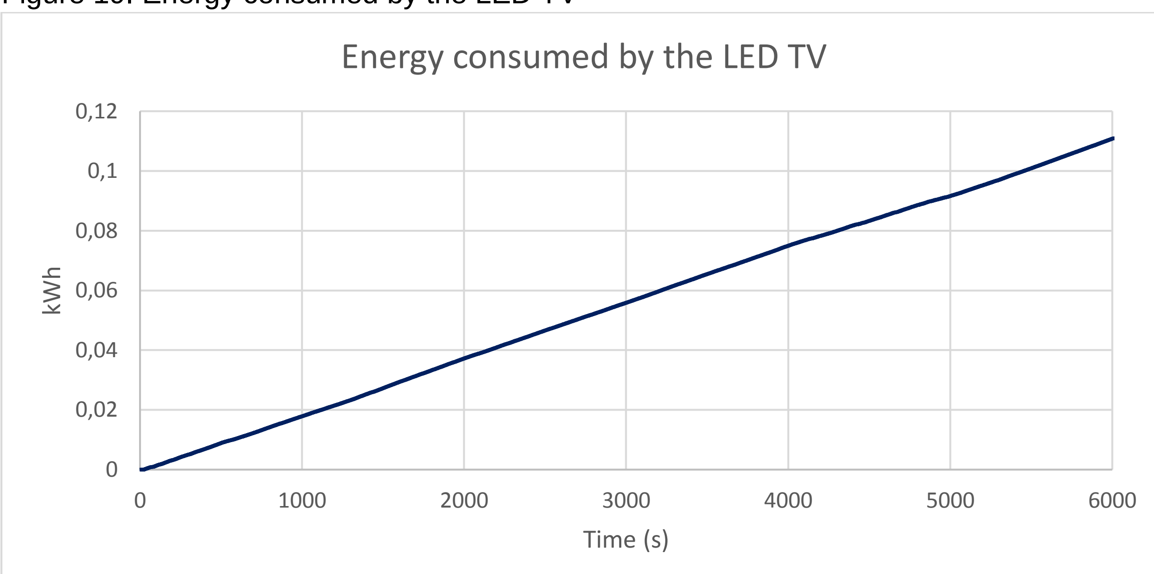
The LED TV was chosen to be measured because it is probably to be the most used appliance at home. In the Figure 18, the current generated by the LED TV is shown, varying from 700mA to 300mA, depending on the quality of image, the sound, intensity and type of color projected. The energy consumed through time is shown in the Figure 19. According to the data collected, the LED TV consumed 0,11kWh during 6018s.

Figure 18. Current generated by the LED TV



Source: The author

Figure 19. Energy consumed by the LED TV



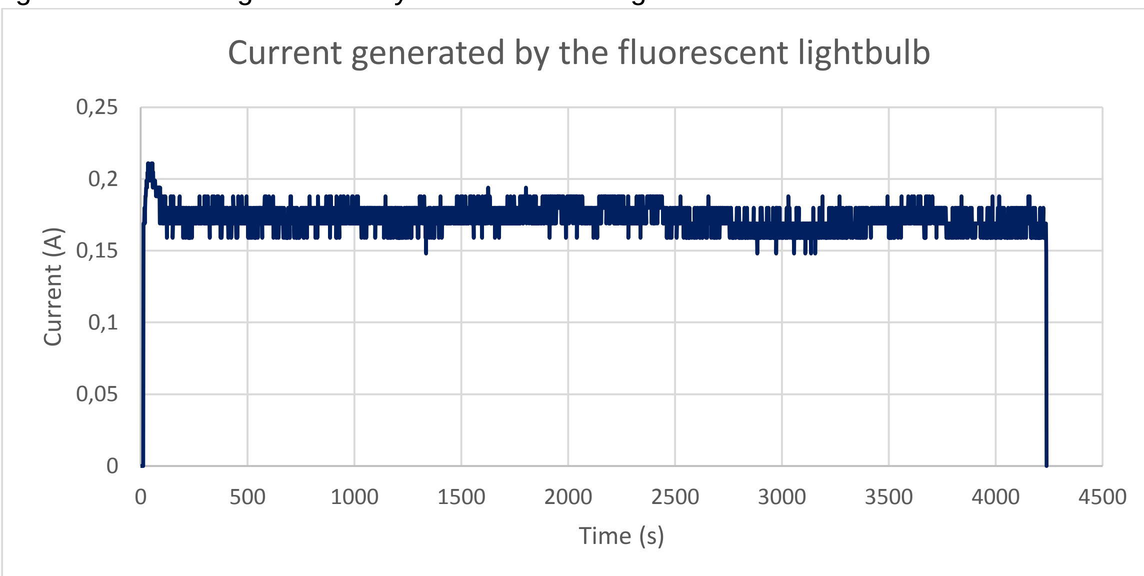
Source: The author

5.5 FLUORESCENT LIGHTBULB

The fluorescent lightbulbs are considered as the replacements of the old incandescent lightbulb, which consumed even 5 times less than these do. These bulbs irradiate less heat, and provide a better illumination. The tested lightbulb is a

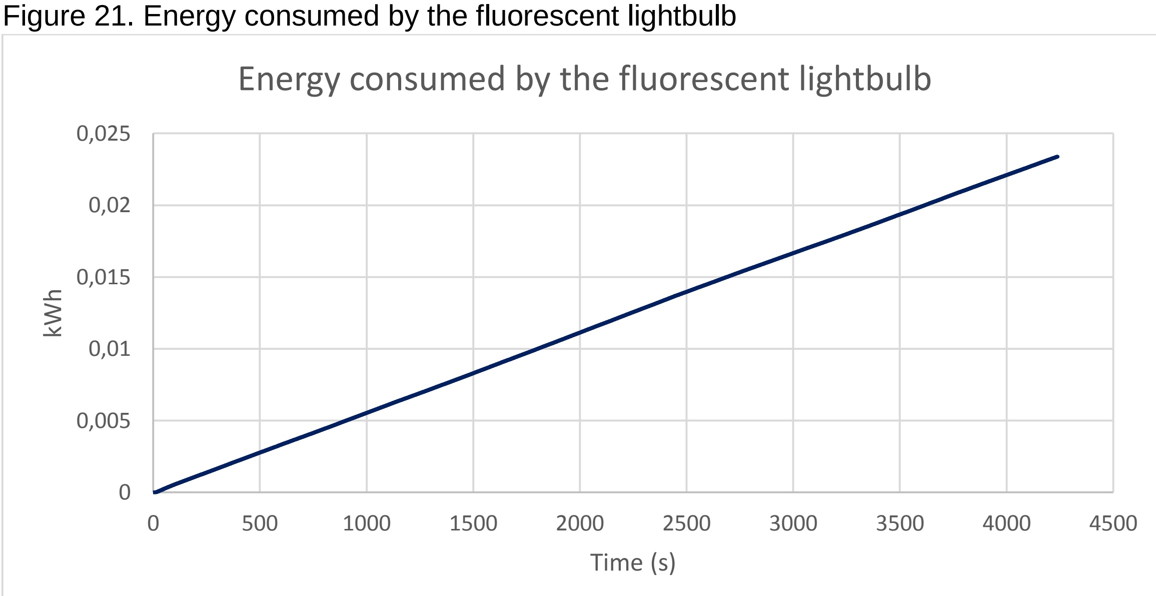
20W of consumption, manufactured by Sylvania. This element was chosen to measure because it is in every single home, in multiple occasions. In the Figure 20, it can be observed that the average of the current generated is around 0,18A, starting from 2,2A, while the energy consumed is graphed in the Figure 21. According to the data collected, the fluorescent lightbulb consumed 0,023kWh during 4219s.

Figure 20. Current generated by the fluorescent lightbulb



Source: The author

Figure 21. Energy consumed by the fluorescent lightbulb



Source: The author

6 DESIGN OF THE POWER AND ELECTRONIC CIRCUITS

In this chapter, the whole implementation of the power stage, sensors, amplification and treatments of signals, transmission and reception of data and communication protocol is described below, and some documentation of the elements and hardware used to bring off the monitoring system.

6.1 POWER STAGE

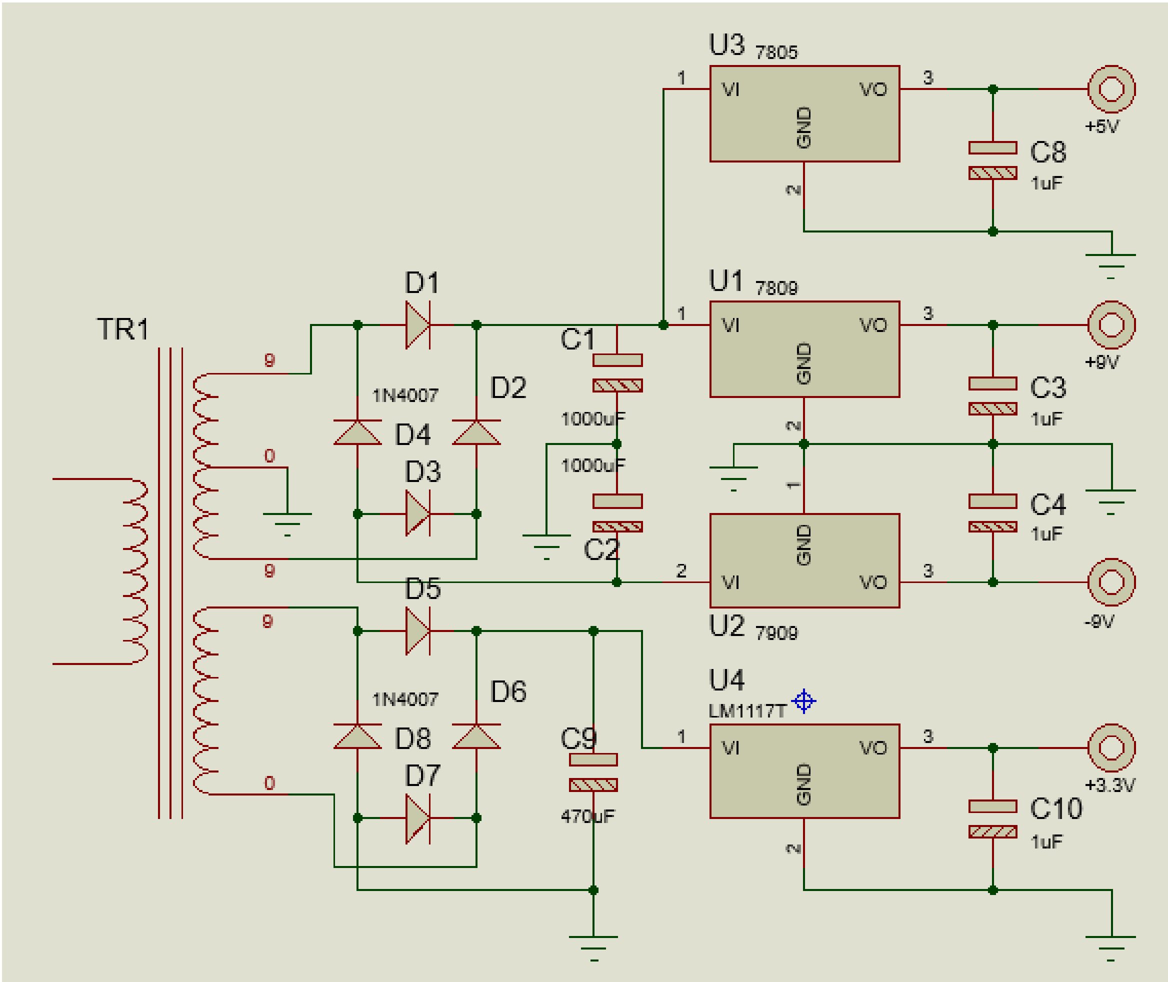
The power stage depends on how much current the electronic circuit, the Arduino and the Wi-Fi module require to work properly. The electronic circuit consumes up to 90mA, while the Wi-Fi module when starting, needs almost 300mA. In addition, the operational amplifier needs ±9V dual supplies to guarantee a 5V output to take into the ADC converter.

To provide the necessary current and voltage, a 9V – 1A transformer is required, which has a center tap to get a dual voltage. This transformer is connected to a diode bridge to rectify the AC current into DC current, followed by two capacitors to smooth the variation of the voltage, the ripple. Now, having the continuous 12V, it is connected to three different regulators to obtain three different voltage levels: ±9V, +5V and +3,3V. The ±9V is supplied to the operational amplifier, so its output could reach 5V. The microcontroller and the Hall Effect current sensor work at 5V, and finally the Wi-Fi module requires 3,3V to operate.

After some tests, it could be seen that there were some troubles when the Wi-Fi module was connected. Apparently, some harmonics were generated and they could not be eliminated using filters, so it was decided to change the type of transformer. The idea was to make independent the ground of the operational amplifier and the microcontroller, from the ground of the Wi-Fi module, by adding a second secondary winding, of 5V – 1A. After rectifying and filtering, the grounds of both secondary voltage sources were shared. In the figure 22, it can be seen the schematic circuit of the power stage.

The capacitors in the outputs are used to maintain the stability of the regulators, eliminating the ripple, if any.

Figure 22. Power stage schematic circuit



Source: The author

6.2 ELECTRONIC CIRCUIT

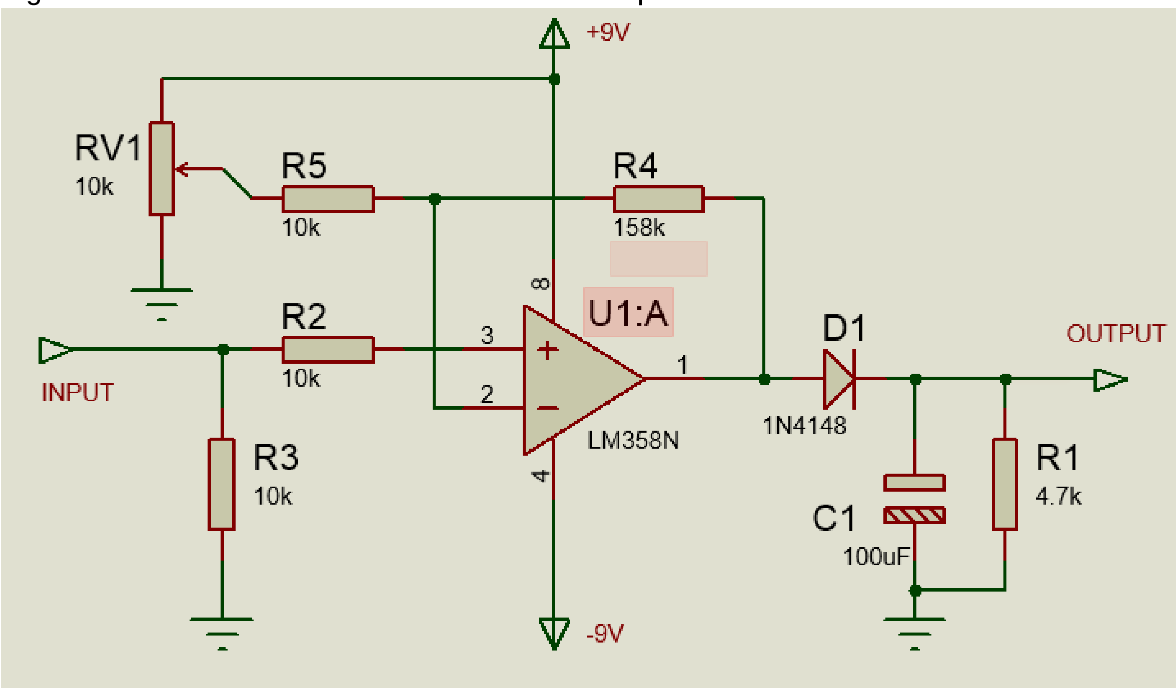
A difference amplifier configuration is set to amplify the difference between a variable voltage level and the sensor output. Later on, the operational amplifier output must be filtered and rectified with a capacitor and a diode because the signal from the sensor is AC due to the measuring of AC current, to finally be taken into the Arduino ADC.

These Hall Effect sensors are especially made for DC, not AC. These devices manufactured for single polarity produce a center voltage of 2.5 volts (if supply is at 5V) with no magnetic field. While connecting an AC signal simply produces about a 4-volt peak-to-peak sine wave (at maximum current) centered at 2.5VDC, but on the AC voltage it just reaches up to 1.4V at best. The difference amplifier setting rejects the DC bias and amplifies the signal, while compensates the voltage loss on the diode that rectifies at the output and finally filter the remaining AC, to obtain a 0-5V output. (Loflin, s.f.)

According to the selected appliances in Chapter 5, it will be required two 5A sensors and three 20A sensors.

6.2.1 5A sensor: The differential amplifier configuration is supplied at ±9V to guarantee a 0-5V output. The input is connected through a pair of resistors to the positive terminal of the operational amplifier. The negative terminal is connected to a 10kΩ potentiometer to adjust the other input voltage. At the same time, this adjustment regulates the gain with the 158kΩ resistor. A germanium switching diode is connected to the output to rectify the signal and in parallel with an electrolytic 100µF capacitor, to filter the ripple. From this point, the output varies from 0 to 5V according to the input signal, and is ready to be converted into a digital signal. In the Figure 23, the schematic circuit is shown.

Figure 23. Schematic circuit of the differential amplifier for the 5A ACS712 sensor

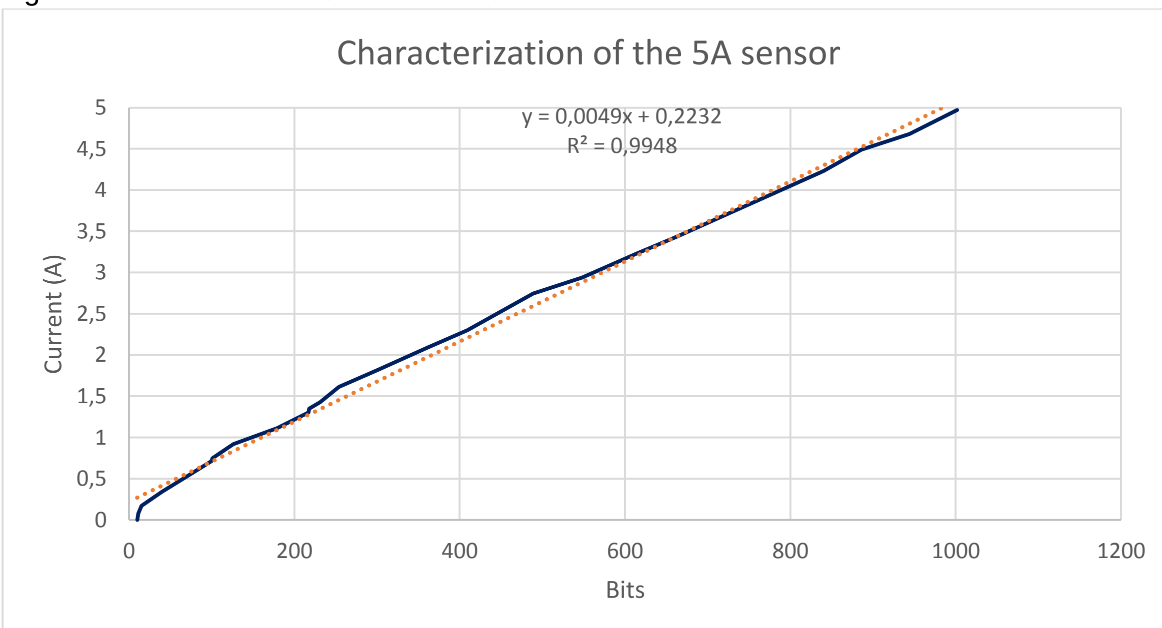


Source: The author

To characterize the sensor, it is important to count with a variable 110V power supply to vary the current that needs an appliance to work, or vary the load on 110V sourced

circuit. While there is no current flowing through the sensor, the potentiometer must be adjusted to 1.386V approximately and the output must be around 58mV, so the minimum amperage is set, being 0A meaning 10 bits. Then, the power supply is adjusted so the circuit consumes 5A and the sensor is connected in series, to set the maximum amperage, being 5A equal to 1023 bits.
An initial value of 10 bits was chosen because the response of the sensor to low currents is not really good, and it is considered as a dead zone. In the Figure 24, the characterization of the 5A sensor is graphed.

Figure 24. Characterization of the 5A sensor



Source: The author

The equation of the 5A sensor is:

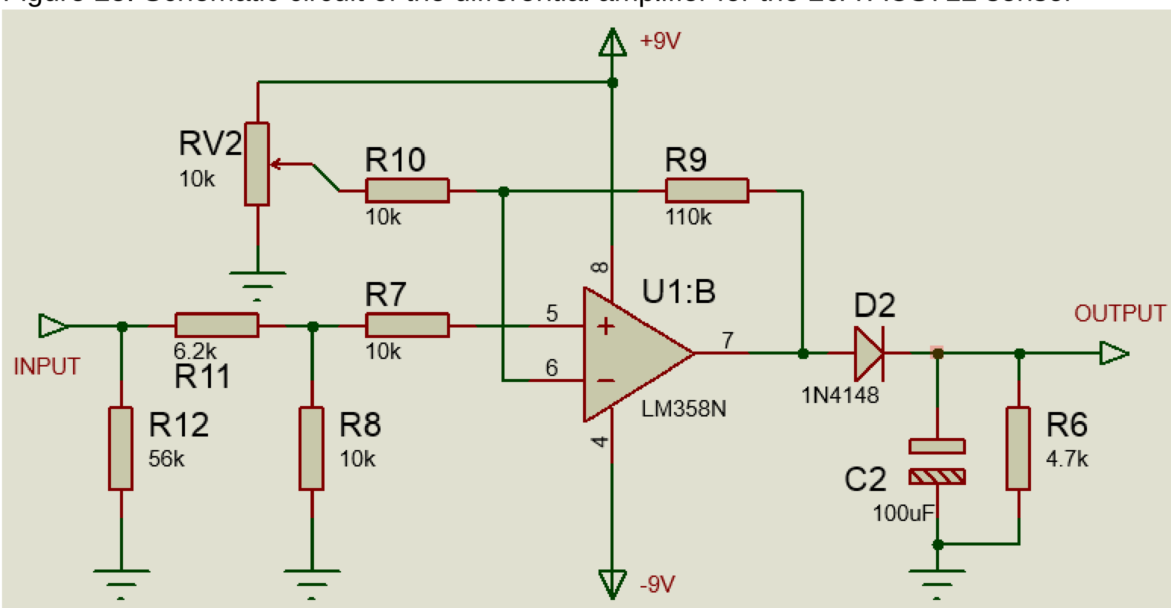
$$y = 0{,}0049x + 0{,}2232$$

It can be seen from the Figure 23 that the response to low currents (500mA and less) is not lineal as the rest of the graphed line, despite the slope value. To correct and to improve the precision of the sensor, after making some test, it was decided to take some sectors of data and take them as a unique graph, obtaining some other equations, between intervals, sectioning the function and improving the precision of the sensor. Below, the selected intervals from 0 to 1023, being *x* bits and *y* current:

if x<=10	y=0
if x>=11 && x<=100	y=(0.0068*x)+0.0446
if x>=101 && x<=217	y=(0.0046*x)+0.3124
if x>=218 && x<=1023	y=(0.0045*x)+0.4333

6.2.2 20A sensor: The configuration for the 20A sensor is the same that the 5A sensor, but with two modifications: a voltage divider after the output of the ACS712 is required to reduce the voltage input to the circuit, and also the feedback resistor is replaced by a 110kΩ, to reduce the gain. The Figure 25 shows the schematic circuit of the 20A sensor.

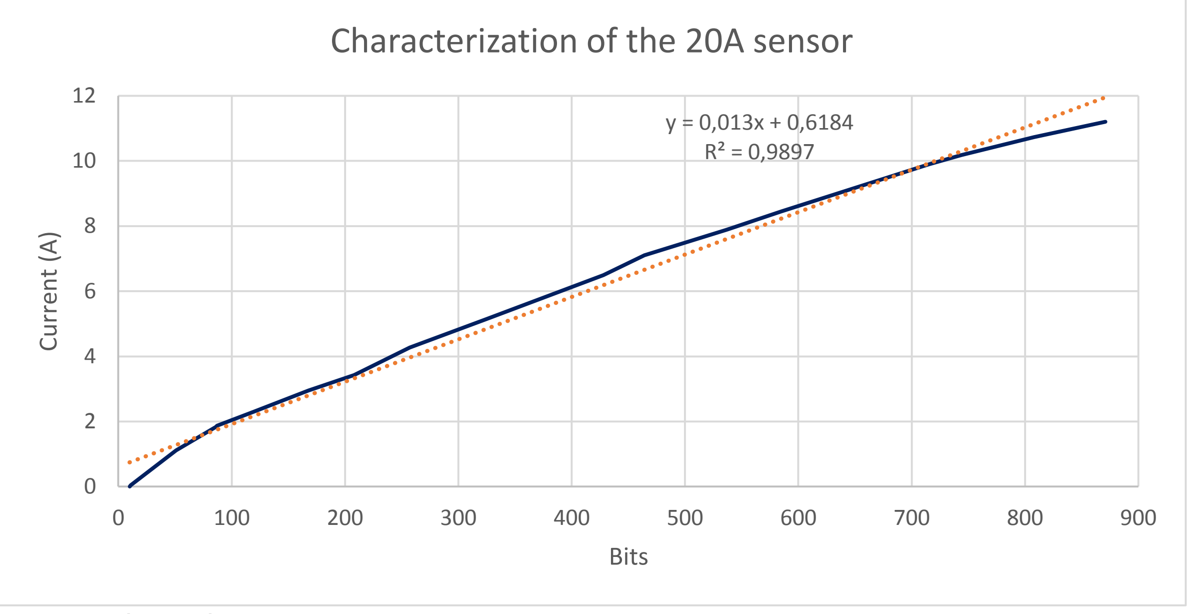
Figure 25. Schematic circuit of the differential amplifier for the 20A ACS712 sensor



Source: The author

The characterization takes the same steps from the 5A sensor. The graph of the sensor can be seen in the Figure 26.

Figure 26. Characterization of the 20A sensor



Source: The author

The equation of the 20A sensor is:

$$y = 0{,}013x + 0{,}6184$$

It can be seen from the Figure 25 that the response to low currents (1A and less) is not lineal as the rest of the graphed line, despite the slope value. The same solution is made to correct and improve the precision from the 5A sensor. Below, the selected intervals from 0 to 1023, being *x* bits and *y* current:

if x<=10	y=0
if x>=11 && x<=86	y=(0.0239*x)-0.1826
If x>=87 && x<=463	y=(0.0138*x)+0.6452
if x>=464 && x<=1023	y=(0.0103*x)+2.4075

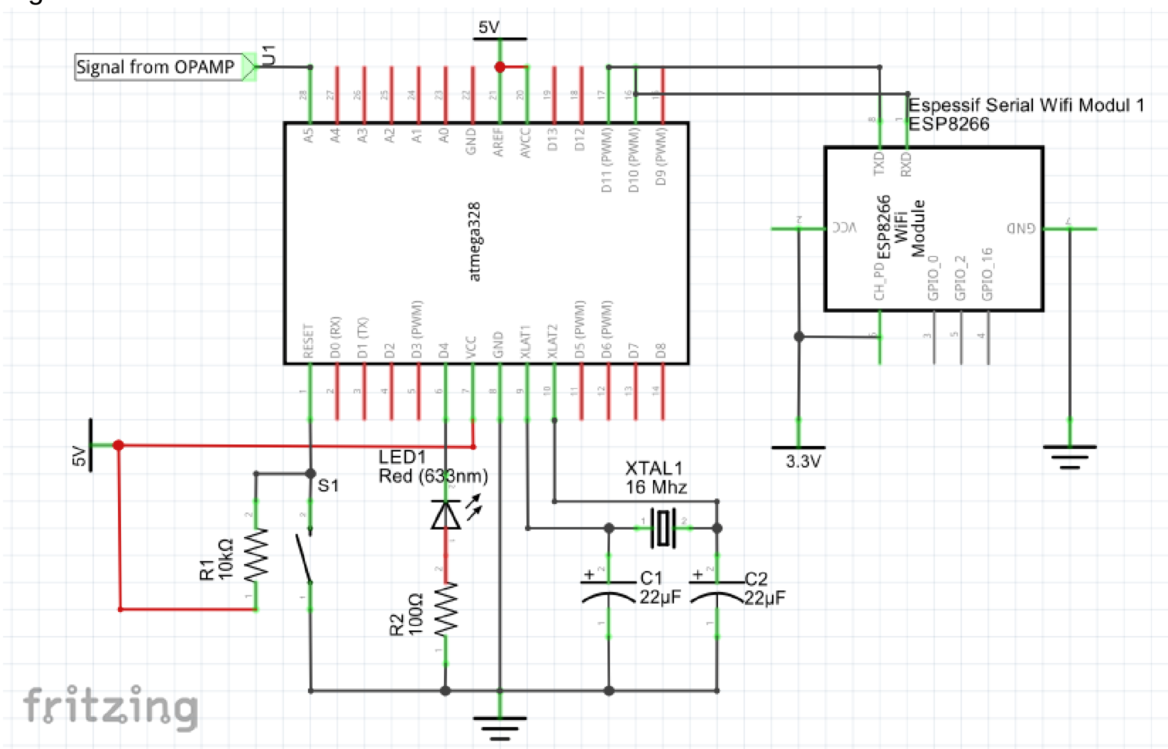
6.3 MICROCONTROLLER ATMEGA328P AND WI-FI MODULE

The microcontroller is the ATMEGA328P, the one used in the Arduino UNO board. This chip was chosen because it can be programmed easily and quickly through the Arduino software and language, and allows to take it out from the Arduino board and to be placed on a printed circuit board, most known as an Arduino Standalone, after being bootloaded. The chip also needs its quartz crystal and capacitors to generate the external oscillation (clock) and the resistor to VCC in the reset pin.

The main function of the microcontroller is to receive de analog data, convert it using its ADC and send the proper AT commands to the ESP8266 so the data can be stored in a database. These connections can be appreciated in the Figure 27.

The ESP8266 module has 8 pins, where 5 of them are needed to connect. The VCC and GND pins to operate, TXD and RXD to establish the serial communication with the microcontroller and the CH_PD pin that enables the Wi-Fi, and needs to be pulled up directly to 3,3V.

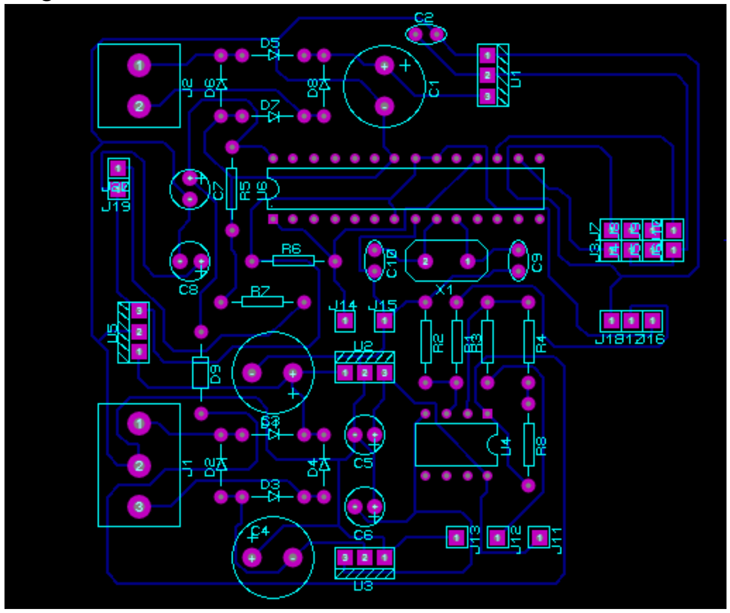
Figure 27. Schematic circuit of the ATMEGA 328 and the ESP8266 Wi-Fi module



Source: The author

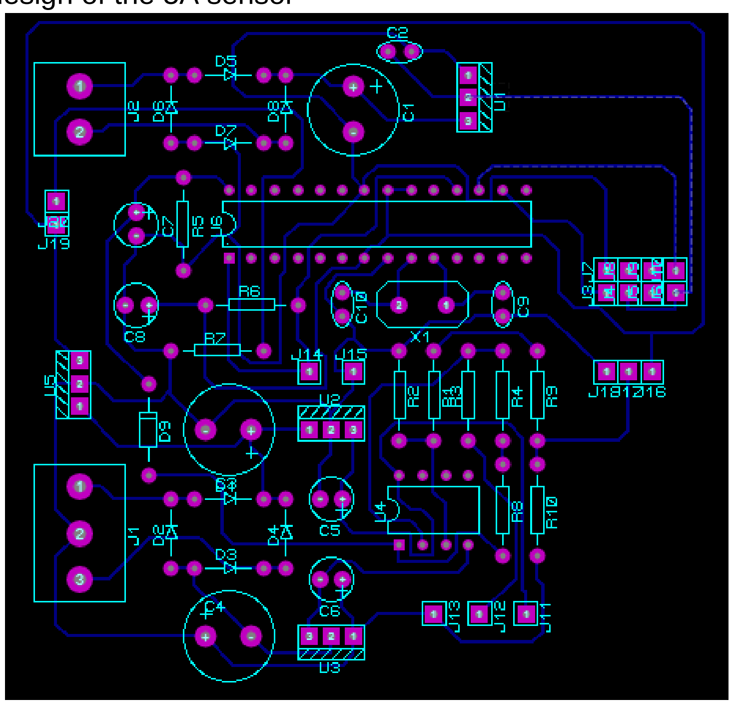
Using the program Proteus 8, the design of the PCB was made. In the Figure 28, the routes and elements of the 5A sensor for the monitoring system is shown, while the Figure 29 presents the PCB design of the 20A sensor. The 3D image of all the components placed on the PCB is depicted in the Figure 30, which was also obtained from Proteus 8.

Figure 28. PCB design of the 5A sensor



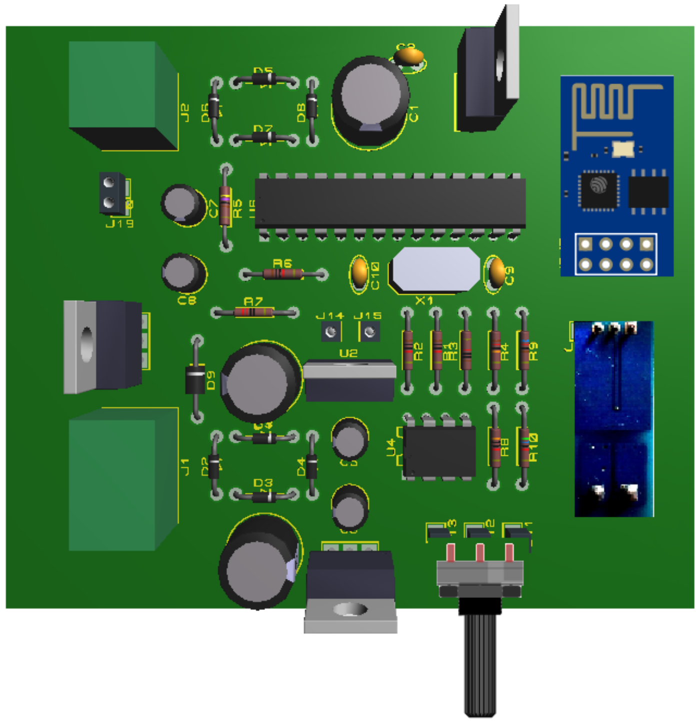
Source: The author

Figure 29. PCB design of the 5A sensor



Source: The author

Figure 30. 3D representation of the sensor's components



Source: The author

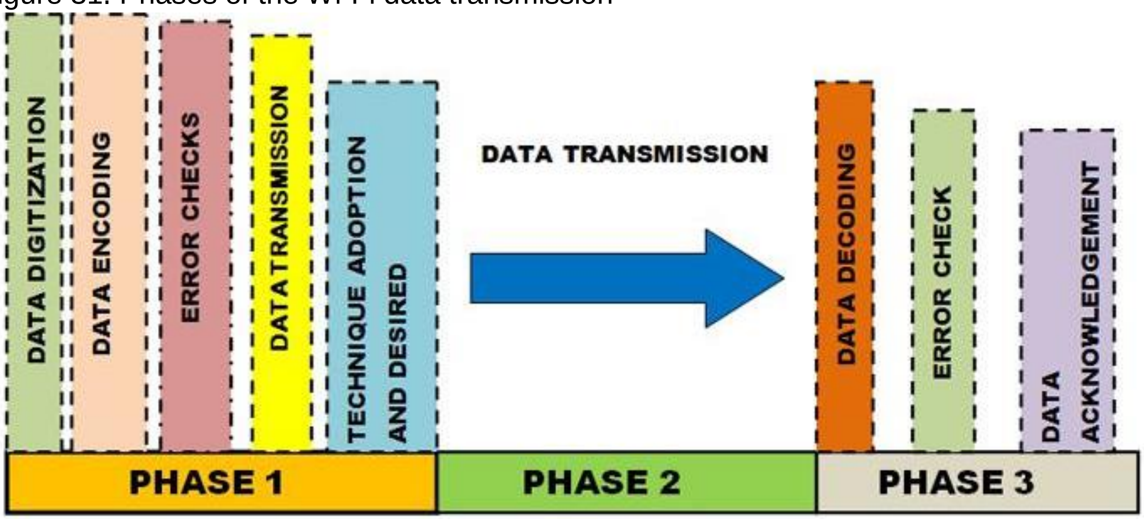
7 PROTOCOL COMMUNICATION

This chapter presents the structure of the program that allows the sensor to send the data and the different files and codes that receives the server to store and show in the database to the user. Also, the connection of the whole system is presented in a plan.

7.1 WI-FI COMMUNICATION

Being the Wi-Fi protocol a wireless communication networking system that allows to send and receive data in a unicast or broadcast way, it is necessary to have at least two devices or systems to establish some kind of communication. The Figure 31 shows a basic schema of how Wi-Fi protocol works, divided in three phases.

Figure 31. Phases of the Wi-Fi data transmission



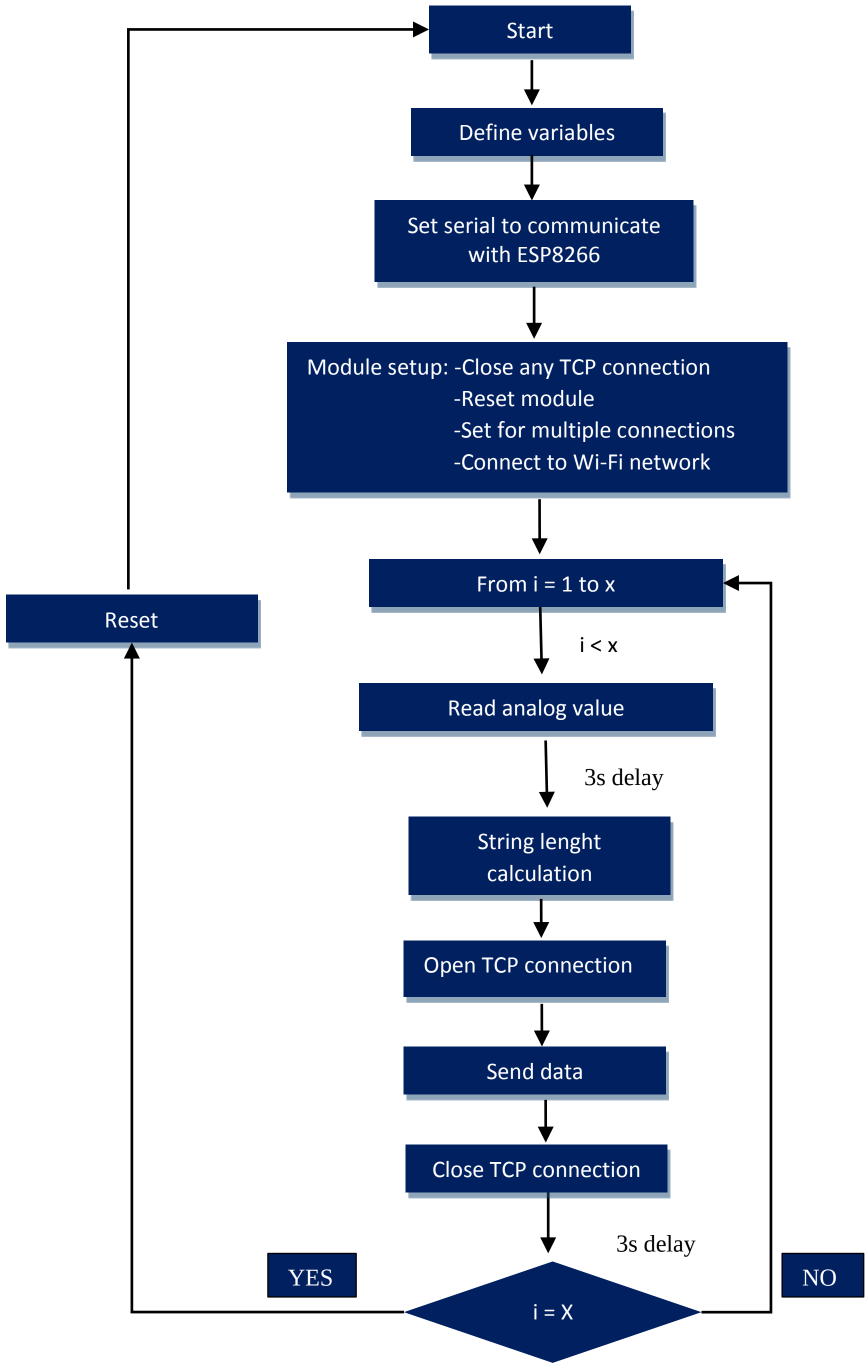
Source: (Enginner's Garage, 2012)

In phase 1, the data is encoded and changed into frames or digital signals and the frequency for the transmission is also chosen by the emitter device, in this case the ESP8266 module. Phase 2 is the data transmission through the air, as medium of wave transmission, and finally the Phase 3 is the reception of the data by the Wi-Fi card installed in the computer, that allows to decode the information. (Enginner's Garage, 2012)

7.2 FLUX DIAGRAM OF THE PROGRAM

In the Figure 32, a flux diagram of the program that is uploaded to the Arduino is posted, so the reader of this document can basically understand, step by step, what the program is about.

Figure 32. Flux diagram of the ATMEGA 328 program



Source: The author

The electrical plan of the sensors can be found in the Appendix J.

7.3 ARDUINO PROGRAM

The code below allows to receive the data from the sensor, runs the protocol to connect the Wi-Fi module to the wireless network and starts sending the string's instructions to send the data to the database.

```
#include <SoftwareSerial.h> //Library that allows to have other serial communications
#define DEBUG true // DEBUG constant with TRUE value
#define HOST "192.168.0.7" // HOST constant with the IP server
int x=0; // "x" integer variable initialized as zero
int resetPin = 12; // Pin to make the reset

SoftwareSerial esp8266(10,11); // Digital pins assigned to make serial communication with the
ESP8266// 10 the RX while 11 the TX// The esp8266 is the name of the serial communication
void setup()
{
 digitalWrite(resetPin, HIGH);
 delay(200);
 pinMode(resetPin, OUTPUT); //resetPin set as a digital output
 Serial.begin(9600); // Arduino serial initialization at 9600 bauds
 esp8266.begin(9600); // Esp8266 serial initialization at 9600 bauds
 sendData("AT+CIPCLOSE=4\r\n",2000,DEBUG); // Closes any TCP connection if opened
 sendData("AT+RST\r\n",2000,DEBUG); // Reset module
 sendData("AT+CWMODE=3\r\n",1000,DEBUG); // Sets module as an access point
 sendData("AT+CIPMUX=1\r\n",1000,DEBUG); // Sets module for multiple TCP connections
 sendData("AT+CWJAP=\"SANTA ISABEL\",\"antonio725\"\r\n",10000,DEBUG); // Connection to
W-iFi network using SSID and PASS
 sendData("AT+CIFSR\r\n",1000,DEBUG); // Shows IP address
}

void loop()
{
 for (int i=0; i<=100; i+=1){ // For cycle from 0 to 100
 int AM = analogRead(A5); // Declares AM as the analog variable A5 ATMEGA Pin
 delay(5000); // Waits 1 second

 //TCP CONNECTION

 //String Lenght calculation
   String webpage = "GET http://192.168.0.5/connection.php"; // A "webpage" string is
concatenated with the php file address
   webpage += "?corriente="; // Adds to "webpage" string the variable name of the php
```

```
  webpage += AM; // Adds to "webpage" string the analog variable
  webpage += "\r\n"; // Adds to "webpage" string the ENTER key equivalent
  Serial.println(webpage.length()); // Prints the lenght of the "webpage" string

 //Open TCP connection
  String cmd = "AT+CIPSTART=4,\"TCP\",\""; // A "cmd" string is concatenated with ID
connection=4, and TCP connection
  cmd += HOST; // Adds to "cmd" string the HOST variable declared
  cmd += "\",80\r\n"; //Adds to "cmd" string the port
  sendData(cmd,1000,DEBUG); // Calls the sendData function
  delay(1000); // Waits 1 second

 //Send TCP data
  cmd = "AT+CIPSEND=4,"; // The same string is concatenated with the command to senda data
and the ID connection
  cmd += webpage.length(); // Adds to "cmd" string the length of the "webpage" string
  cmd += "\r\n"; // Adds to "cmd" string the ENTER key equivalent
  sendData(cmd,1000,DEBUG); // Calls the sendData function
  delay(1000); // Waits 1 second

 //Send data to database
  sendData(webpage,1000,DEBUG); //Calls the sendData function to send the "webpage" string
  delay(1000); // Waits 1 second

 //Closes connection
  sendData("AT+CIPCLOSE=4\r\n",1000,DEBUG); // Closes the TCP connection

if (i>98){
      delay(10);
      digitalWrite(resetPin, LOW); // Statement that allows to reset the microcontroller
}

//FUNCTION SENDDATA
String sendData(String command, const int timeout, boolean debug) // String, time and response
{
 String response = "";

  esp8266.print(command); // Send the read character to the ESP8266
  long int time = millis();
  while( (time+timeout) > millis())
  {
   while(esp8266.available())
   {
    // The esp has data so display its output to the serial window
    char c = esp8266.read(); // read the next character.
    response+=c;
```

```
    }
  }
  if(debug)
  {
    Serial.print(response);
  }
  return response;
}
```

Basically, the setup begins with the configuration of the ESP8266 Wi-Fi module, establishing ports, connecting with the wireless network and IP address of the server. Then, the microcontroller reads the analog input from the transducer, converts it into digital data using the ADC converter and string sentences are executed, indicating the route of the php file that establishes the connection between the server and the database, and finally the data is aimed and stored in the selected table, according to the php file SQL sentences. This process repeats itself until a FOR cycle ends, and the microcontroller reboots itself and starts over.

7.4 COMMUNICATION BETWEEN SENSORS AND DATABASE

The communication between the database and the sensors results when the program, previously presented, runs in the microcontroller. When the chip runs the string sentence *"GET http://192.168.0.5/connection.php"*, indicating the IP server and the address of a PHP file, that contains statements to connect to the database and fill the tables in it. In the code below, the PHP used to communicate the sensor with the database is explained detailed.

```
<?php
include 'conexion20a.php'; // The PHP file to connect the database is included (explained below this code)
date_default_timezone_set('America/Bogota'); The timezone for Bogota is established
$date = date('Y-m-d H:i:s'); //A “date” variable is assigned with the actual date and hour
$v=(115); //Value of the voltage assigned to the “v” variable
$hour = (1/3600); // Value to obtain kW per second
$y=(0); // A “y” variable is assigned with a null value
$kwh=(0); // A “kwh” variable is assigned with a null value
$x = ($_GET["corriente"]); //The variable from the microcontroller is assigned to the variable “x”

//Section to turn bits (x) into amperes (y)
if ($x<=10){
$y=0;}
else if ($x>=11 && $x<=86){
```

```
$y=((0.0239*$x)-0.1872);}
else if ($x>=87 && $x<=463){
$y=((0.0138*$x)+0.6452);}
else if ($x>=464){
$y=((0.0103*$x)+2.4075);}

$w = (($y * $v)/1000); // Equation to obtain watts (kW=V*I/1000)
$wh = ($w * $hour); // Equation to obtain kWh
$kwh = $kw + $w; // Cumulative sum of kilowatts
$price = $kwh * 409.8; // Being 409.8 the price of kWh, formula to obtain the price

mysql_query ("INSERT INTO sensor1 (current1,kwh1,price1,time1,bits1) VALUES ('$y','$kwh','$price','$date','$x')",$link); // Request to insert into the Table 'sensor1', the values of current, kWh, price of kWh and bits

@mysql_close($conexion20a); // Close connection of the database
?>
```

The file first calls the statement to establish a connection to the database (expressed in the following code). After that, several variables are declared, and there is a request of the maximum value of kwh registered in the database so far, so it can be added to the next register and a cumulative sum, is to say, a real-time consume of kWh can be later visualized. Later on, the calculation of the current is made according to the intervals established in Section 6.2.2 and the wattage and energy consumed by hour can be also calculated. Finally, all these information is sent to the database, specifying the database, table and columns. The following code is the PHP file that is called to open the connection with the database.

```
<?php
$link = mysql_connect("localhost","root",""); // The server name, username and password are declared and called
mysql_select_db("ems",$link); // The database 'ems' is called to make the connection
?>
//In this moment, the connection with the database is already established
```

In the main folder of the server, where all the files concerning the database and the webpage are located one of each of these PHP files per sensor, that is to say there is a unique PHP file that makes the connection with the database and the PHP file required by the Arduino program, per sensor.
Having a php file for establishing connection for every sensor, it can exist communication and storage of data at the same time, with all the sensors connected at a time.

8 MONITORING SYSTEM

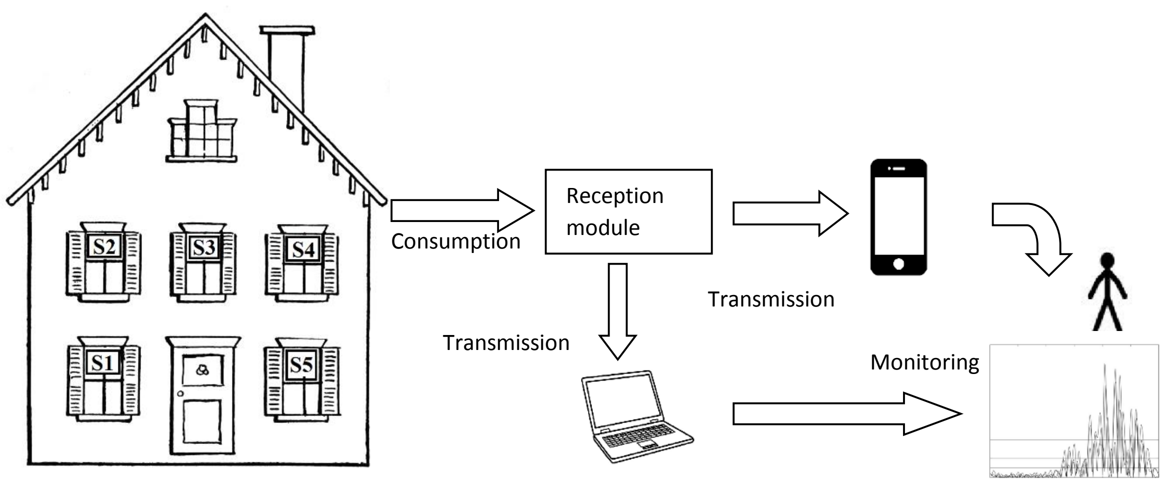
A design and implementation of a real-time monitoring system is designed to see the consumption of electric energy, in kilowatts per hour, and at the same time the price in Colombian pesos of what has been consumed, to reduce the environmental impact and the cost of the electricity bill.

8.1 GENERAL ANALYSIS

The system will have five electric nodes to measure the consumption of electric energy, which will transmit their data to a database, being able to be monitored through a graphic interface.

In the Figure 33, it can be appreciated a quick and simple sketch of the desirable monitoring system to be implemented. The house has five electric nodes, represented with sensors from S1 to S5. The obtained data from these sensors will be sent and stored into a database. These data, consumed kWh and pesos per kWh, after being calculated, finally will be able to be seen in a mobile phone or a webpage in a computer, from the database.

Figure 33. Sketch of the monitoring system



Source: The author

8.2 PROFILES

The system counts with two profiles:

- User: the system is aimed for the users, to check the status and performance of their appliances, from everywhere since they are connected to the Internet. It makes the system to have a basic security level to protect and make confident all the data. The user does not have permission to make any change, but to setup and to monitor data.
- Admin: Only manages the user information.

8.3 REQUIREMENTS

The requirements for the monitoring system are shown and classified in tables, using the format shown in the Table 5, with the detailed information.

Table 5. Requirements format table

Title:	
Code:	
Priority:	Status:
Author:	Role:
Description:	
Related requirements:	
Source: The author	

where:

- Title: Requirement name
- Code: Requirement identification. Unique parametrization with the following form: “FR - ##” or “NFR - ##”; FR means ‘Functional requirement’ and NFR ‘Not functional requirement’, and the following characters are the number assigned.
- Priority: Implementation order of the requirements. High, medium or low.
- Status: Situation of the requirement in the application. Implemented or not implemented.
- Author: Person who wrote the requirement.
- Role: Roles that can be assumed.
- Description: Detailed explanation of the requirement.
- Related requirements: List of requirements that may be related.

8.3.1 Users: The tables 6, 7 and 8 are shown the requirements that are needed to login and validate the information to access the monitoring system.

Table 6. Requirement to access the system

Title: Access to the monitoring system	
Code: FR-01	
Priority: High	Status: Implemented
Author:	Role: DNA
Description: To access into the application, a username and a password are mandatory. Once submitted, the system validates them: • If the username or the password are wrong, an error message pops up. • If the username and the password are correct, the main window will be accesed.	
Related requirements:	
Source: The author	

Table 7. Requirement of unique user

Title: Unique user checker	
Code: FR-02	
Priority: High	Status: Implemented
Author:	Role: DNA
Description: The username must not be repeated. The system validates its availability.	
Related requirements:	
Source: The author	

Table 8. Requirement for the signed up users

Title: Signed up users	
Code: FR-03	
Priority: High	Status: Implemented
Author:	Role: DNA
Description: The users are signed up in the database, with the following information: • Username • Password The username cannot be changed and the password can only be edited by the admin.	
Related requirements:	
Source: The author	

8.3.2 Webpage interface (HMI): The tables 9 to 13 contain several information according to the visual requirements of the webpage, such as design, and content.

Table 9. Requirement for the executable files

Title: PHP files	
Code: NFR-01	
Priority: High	Status: Implemented
Author:	Role: DNA
Description: The system is based on javascript, PHP, HTML, CSS languages, with PHP executable files.	
Related requirements:	
Source: The author	

Table 10. Requirement for the webpage general design

Title: Common style	
Code: NFR-02	
Priority: High	Status: Implemented
Author:	Role: DNA
Description: All the windows of the webpage have the same appearance and style. The titles are on the top of the windows, with the different options depending on the window.	
Related requirements:	
Source: The author	

Table 11. Requirement for the webpage menu

Title: Menu	
Code: NFR-03	
Priority: High	Status: Implemented
Author:	Role: DNA
Description: The main menu lists the five sensors available, to select and to monitor the behavior of the consumption point, through graphic reports.	
Related requirements:	
Source: The author	

Table 12. Requirement for the webpage's pop ups.

Title: Pop ups	
Code: NFR-04	
Priority: Medium	Status: Implemented
Author:	Role: DNA
Description: Pop ups will appear in some conditions to inform the user about important information while using the webpage.	
Related requirements:	
Source: The author	

Table 13. Requirement for the webpage's error messages

Title: Error messages	
Code: NFR-05	
Priority: High	Status: Implemented
Author:	Role: DNA
Description: Error messages will pop up when some wrong information is submitted, and when the webpage is malfunctioning.	
Related requirements:	
Source: The author	

8.3.3 System and data: The tables 14 to 16 present the information regarding the validation and registration of the webpage for the user, and the relation with the database.

Table 14. Requirement for the registration to access the webpage

Title: User registration	
Code: NFR-06	
Priority: High	Status: Implemented
Author:	Role: DNA
Description: In the registration window, the user must insert his username, password and email, so he can be allowed to enter the system.	
Related requirements:	
Source: The author	

Table 15. Requirement to log in to access the system

Title: User connection and log in	
Code: NFR-07	
Priority: High	Status: Implemented
Author:	Role: DNA
Description: In the login window, the user must type its user and password to access the application.	
Related requirements: NFR-06	
Source: The author	

Table 16. General requirement for the database

Title: Database	
Code: NFR-08	
Priority: High	Status: Implemented
Author:	Role: DNA
Description: The user information is stored in a database, and the data from the sensor already stored is available to be consulted in the menu window.	
Related requirements:NFR-06, NFR-07	
Source: The author	

8.4 USE CASE MODEL

A use case is the summary of some activities performed by an actor (in this case the user) and the system (the webpage) to fulfill a request or a goal. In the Table 17, the use case model of the monitoring system is presented.

Table 17. Use case model of the monitoring system

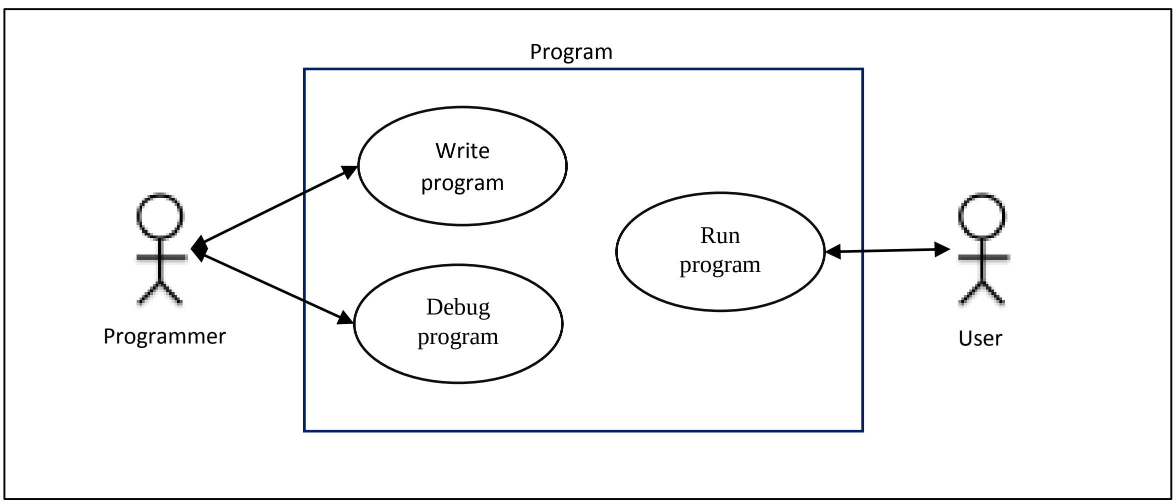
Actor: User	
Use case	Validate user, sign up user, consult information
Type	Primary
Description	One of the main actors and can be represented as any person who wants to use the monitoring system
Actor: Programmer	
Use case	Validate user, sign up user, consult information, edit user information
Type	Primary

Table 17. Use case model of the monitoring system (Continuation)

Description	The main actor with the highest hierarchy, with no restriction and with the authority to consult and edit any information of any user.
Actor: Database	
Use case	Validate user, sign up user
Type	Secondary
Description	
Actor: Mobile phone	
Use case	Validate user, sign up user, consult information
Type	Primary
Description	One of the principal actors that allows any person signed up previously to consult the monitoring system through a mobile phone.
Source: The author	

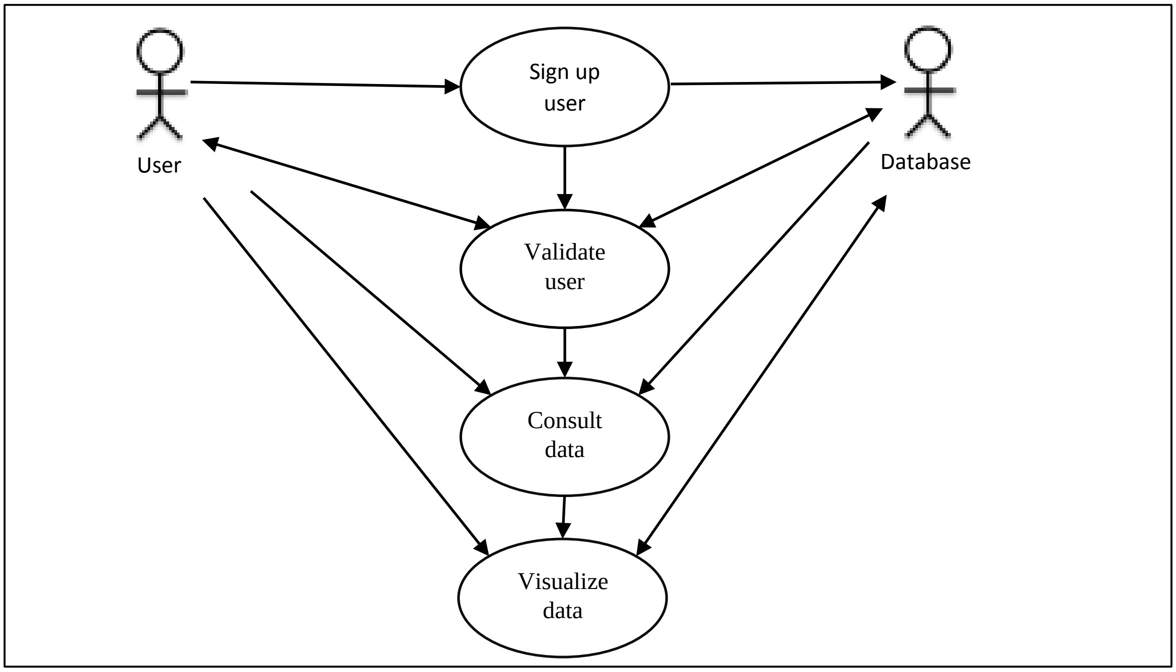
8.4.1 Use case diagrams: The use case diagrams are the representation of the interaction between the users and the system. In the Figure 34, the relation between the programmer and the user is shown, where the programmer sets and prepares the program for the user to run it.

Figure 34. Use case diagram of the actors involved in the system



Source: The author

Figure 35. Use case diagram of the monitoring system



Source: The author

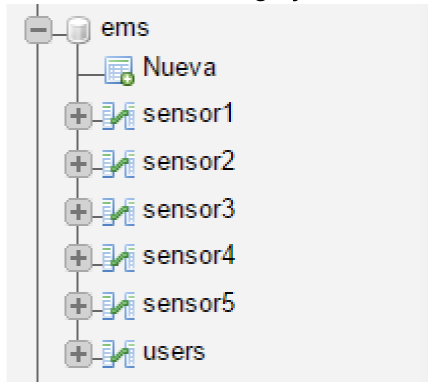
The Figure 35 shows the complete use case diagram. The user needs first to sign up, just once, and then validate its user and password, to be able to consult the chosen appliance and visualize the data in the webpage.

8.5 DATABASE DESIGN

The database can be divided in two different sections: Users' registration and data storage. The user's section is aimed to store only the information of the client so he can log in, monitor his appliances and when finished, log out. The data's section only has the purpose to store the data from the sensors so it can be selected and visualized when the user requires it.

A database called *EMS* (Energy Monitoring System) is created in phpMyAdmin, along with 6 tables: one aimed to store the user's information and the rest, the data from the sensors, as shown in the Figure 36.

Figure 36. Database and tables of the monitoring system



Source: The author

8.5.1 Users' registration: This section of the database refers only to one single table, called *users*, shown in the Figure 37. This table contains the information that the user enters to be allowed to use the system. It counts with an auto increment field, for administrator use and importance only, and basic information of the user to log in and the email so the administrator can contact him or her when necessary.

Figure 37. *Users* table

#	Name	Type	Collation	Attributes	Null	Default	Extra
1	**user_id**	int(11)			No	*None*	AUTO_INCREMENT
2	**username**	varchar(16)	latin1_swedish_ci		Yes	*NULL*	
3	**password**	varchar(255)	latin1_swedish_ci		Yes	*NULL*	
4	**email**	varchar(60)	latin1_swedish_ci		Yes	*NULL*	

Source: The author

8.5.2 Data storage: This part of the database holds the entire data sent from the sensors. Each one of them counts with its own table, and they can be differenced by the number right next to it. These 5 tables count with five fields, so the user can see the current generated while plugged (current), the energy consumed so far (kwh), the cost of the consumption so far (price), the date and hour when the data was taken (time), and the equivalence of the current digitally from 0 to 1023 (bits). In the Figure 38, the table *sensor1* is shown, as an example of the tables assigned to store the data from the sensors.

Figure 38. *Sensor1* table

	#	Nombre	Tipo	Cotejamiento	Atributos	Nulo	Predeterminado
	1	**current**	float			No	*Ninguna*
	2	**kwh**	float			No	*Ninguna*
	3	**price**	float			No	*Ninguna*
	4	**time**	timestamp			No	CURRENT_TIMESTAMP
	5	**bits**	int(4)			No	*Ninguna*

Source: The author

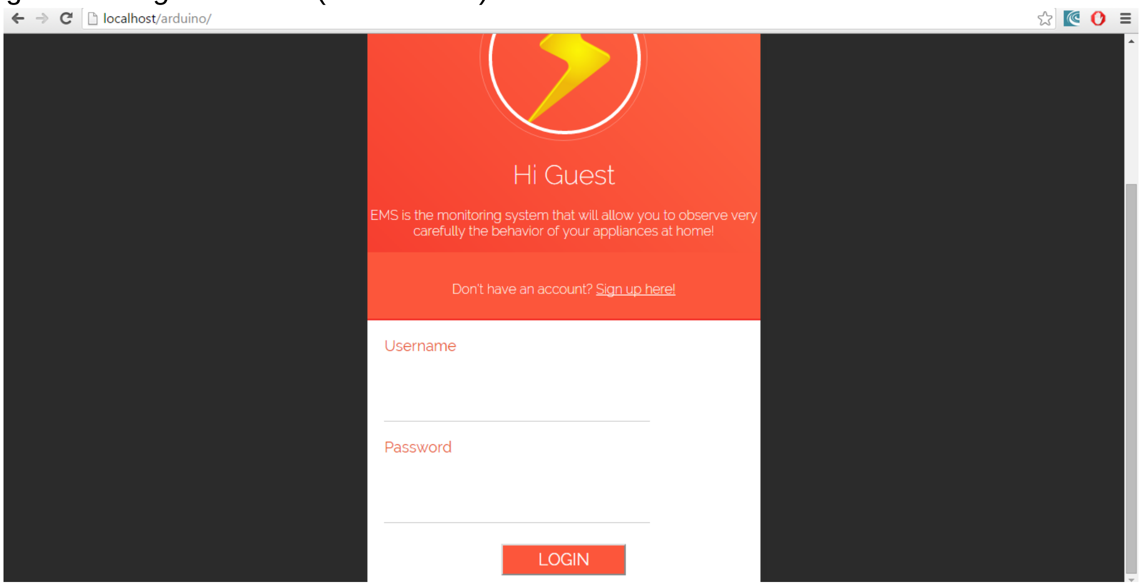
8.6 WEBPAGE DESIGN

The development of the website was accomplished using the program Adobe Dreamweaver CC, and a basic template. Every single page needs to be in PHP language, so it can be linked to the database. The whole monitoring system is based and implemented in a local network and server, XAMPP.

The monitoring system is also intended for the user to be consulted using a mobile phone or a tablet, so the template used is a responsive CSS, which contains additional Javascript files so the window adjusts itself to the device it is being consulted. Several screenshots from the Monitoring System window, taken from a Huawei Ascend P7 mobile phone, are shown along with the webpage.

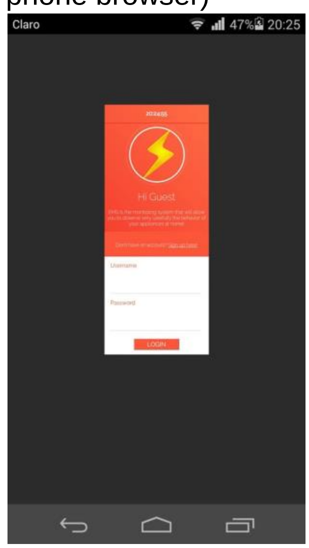
The monitoring system requires basically windows to enter the monitoring system, and to visualize the data stored in the database. Three form elements are presented in this window, text fields for the username and password and a submit button, for the user to log in. If the user does not have an account yet, there is a link to redirect to the Sign Up window. Finally, a brief description of the monitoring system is posted. If any text field has not been filled yet, a pop-up message informs the user that there is still some fields to fill. The window to log in can be appreciated in the Figure 39 in a PC browser version, while the Figure 40 shows the screenshot of the mobile phone browser, both named *index.php*.

Figure 39. *Log in* window (PC browser)



Source: The author

Figure 40. *Log in* window (Mobile phone browser)

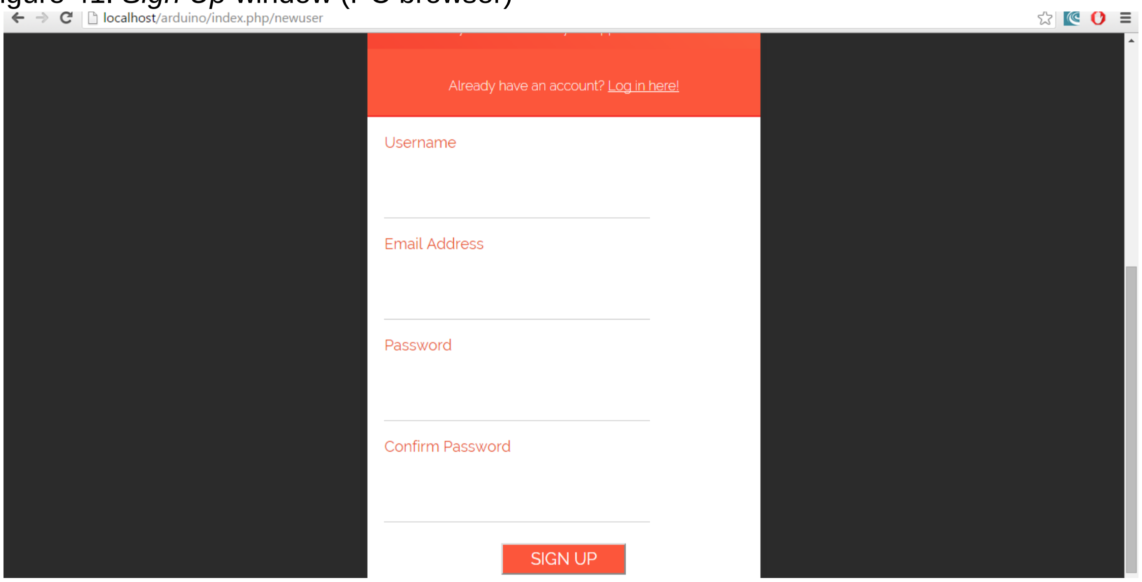


Source: The author

If the user forgets the username or password, he should contact the admin via e-mail, so he can be given a new one.

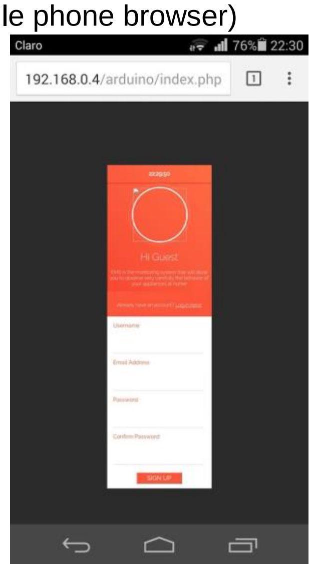
The Figure 41 and 42, shows the Sign Up window in PC and mobile phone browser respectively. It counts with five form elements: four text fields for the username, password, confirm password and email and a submit button to finally submit the information to be allowed to access the monitoring system. The user that has not created an account in this window will not be able to access the monitoring system. It also counts with a link that redirects to the Log In window, if the user already has an account. The same introductory and briefly information of the Log In windows is posted below. If any text field has not been filled yet, a pop-up message informs the user that there is still some fields to fill.

Figure 41. *Sign Up* window (PC browser)



Source: The author

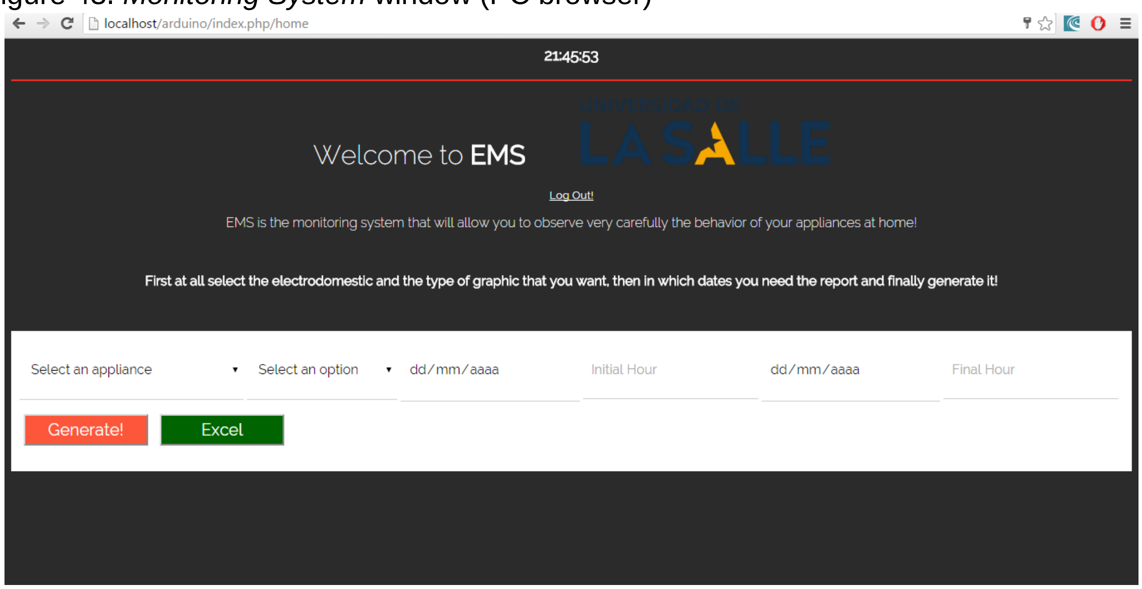
Figure 42. *Sign Up* window (Mobile phone browser)



Source: The author

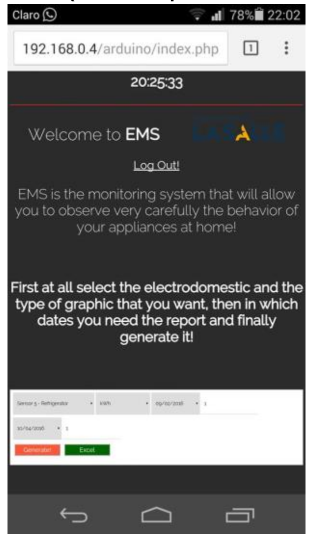
When the user has successfully signed up and logged in, he is allowed to access the monitoring system window, shown in the Figure 40 in PC browser and Figure 41 in mobile phone browser. This window offers the user to select an appliance from a drop-down list depicted in the Figure 43 for PC and Figure 44 for mobile phone with 5 options, one for every sensor. Right next to this list, there are two buttons, that will open a new tab with the energy consumed graph and the consumption cost graph respectively, of the appliance previously selected. There are another two buttons that allow to know the total consumption of kilowatts or COP of the five sensors together so far. It also counts with a Log Out option so the user can close his account safely.

Figure 43. *Monitoring System* window (PC browser)



Source: The author

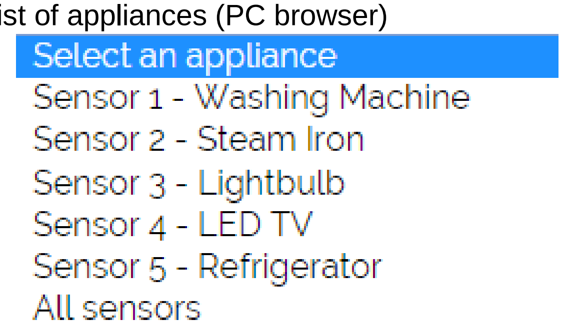
Figure 44. *Monitoring System* window (Mobile phone browser)



Source: The author

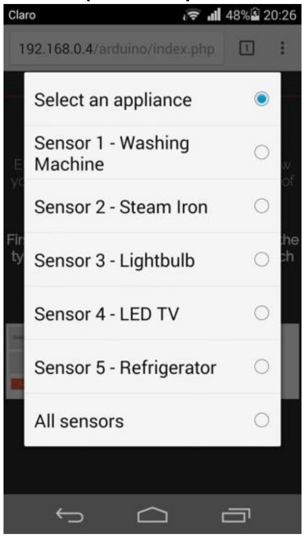
The appliances shown in the drop-down list (Fig. 45 and 46) were already established according to the ones chosen in the Section 5. If they user desires to modify these appliances' names, he should contact the admin via e-mail.

Figure 45. Drop-down list of appliances (PC browser)



Source: The author

Figure 46. Drop-down list of appliances (Mobile phone browser)



Source: The author

After the sensor is selected, additional information is required, such as initial date, initial hour, final date and final hour, along with the energy consumed or price selected. Once all this information is completed, the user can generate the graph of the selected range, from the selected sensor, from the selected option of kWh or COP, by clicking on the “Generate!” button. It can be seen in Fig. 47 for desktop and 48 for mobile phone. It is also capable of export the selected data into an Excel file.

Figure 47. Additional information to generate the graphs (PC browser)

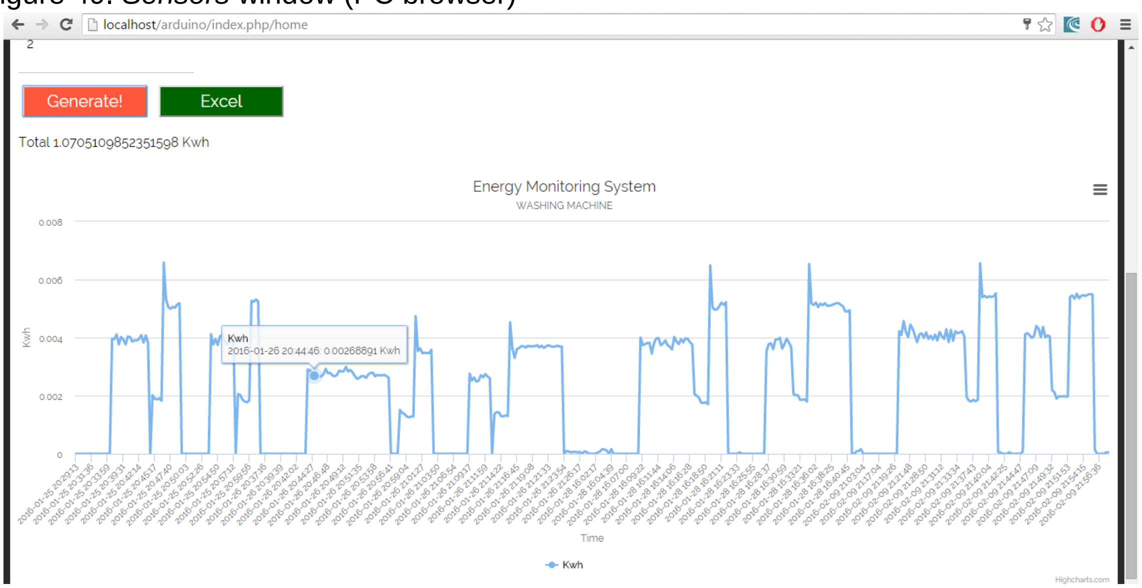
Source: The author

Figure 48. Additional information to generate the graphs (Mobile phone browser)

Source: The author

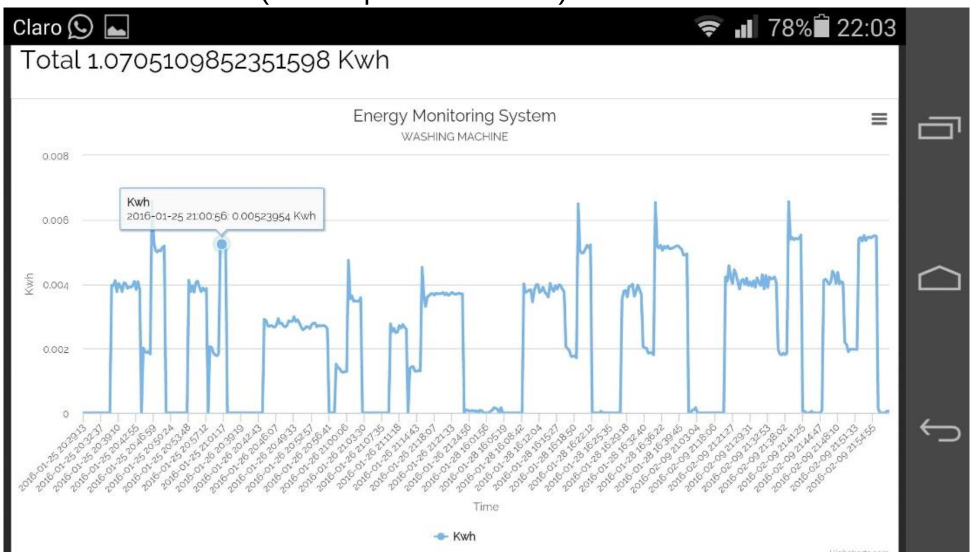
When the “Generate!" button is clicked, the graph appears below, showing the information collected in the database. This graph is generated by using a Javascript library called *Highcharts*, which allows to graph the data that has already collected. This is considered as a dynamic chart, because the graph is not just points graphed and connected to make a line, but the graph shows specific information when the cursor is over any point graphed. In the Figure 49 for PC browser and Figure 50 for mobile phone, the graph shows an example of the data that was stored in the database, the sensor 1 as example, where the dynamic effects can be appreciated.

Figure 49. *Sensors* window (PC browser)



Source: The author

Figure 50. *Sensors* window (Mobile phone browser)



Source: The author

This Javascript library also allows the user to download the graph as a PDF document, PNG image, JPEG image or SVG vector image, and print it as well, by clicking in the button in the right corner that drops down a list to choose.

9 TESTING AND VALIDATION

Once the database is designed and created, the electronic circuits of the sensors are welded in PCBs, the programming of the microcontroller, characterization and the webpage created as well, the tests with the five appliances chosen in Chapter 5 are ready to begin.

To start, it is important to establish a sampling time to carry on the tests for each appliance. An interval of 20 seconds for taking samples is determined and programmed as a delay. It is also necessary to know the voltage so the wattage can be obtained. For that reason, it was required to measure the tension of all the electrical points around the house (sockets) to calculate an average voltage for the testing. In the Table 18, the sum and average of 13 electrical points is shown.

Table 18. Average of voltages

Voltage (V)
120,6
117,5
119,1
117,9
118,2
117,5
118,2
117,5
118,2
118,5
118
117,7
117,6
Average: 118,1923

Source: The author

After knowing the voltage for the tests and the sampling time, it is now possible to obtain the wattage. The objective of this monitoring system is to inform in real time the energy consumed and its cost so far, so the wattage consumed per hour needs to be calculated in seconds, and knowing that the base of the bills is the kWh price, the wattage per hour is calculated every 20 seconds, to have a cumulative sum that allows the user to consult it in real time

$$kWh = \frac{V * I * \frac{1}{3600s} * X}{1000}$$

where kWh = Killowatts per hour
V = Average voltage
I = Current send from the sensor
s = seconds to take the samples
X = interval of samples per seconds

Finally, these kWh value is multiplied with the unitary cost of kWh established by the government, being COL 409.82 to make the test, cost of the kWh for the stratum 3 in November 2015.
With all these data gathered, the cumulated energy consumed and cost of the bill so far, can be consulted by the user through the webpage.

The tests are compared with the data obtained and presented in the Chapter 5. The following graphics were taken from the webpage, generated by the Javascript library Highcharts, and the data plotted from the database.

One of the problems while doing these tests was the stop of sending and receiving information. For the tests of the washing machine, refrigerator, lightbulb and steam iron, the sensor stopped sending data, and it was required to unplug and plug it back again. There is no specific time for the sensors to stop running. The user's manual can be found in Appendix I.

These tests were carried out on December 9^{th} and 10^{th}, 2015.

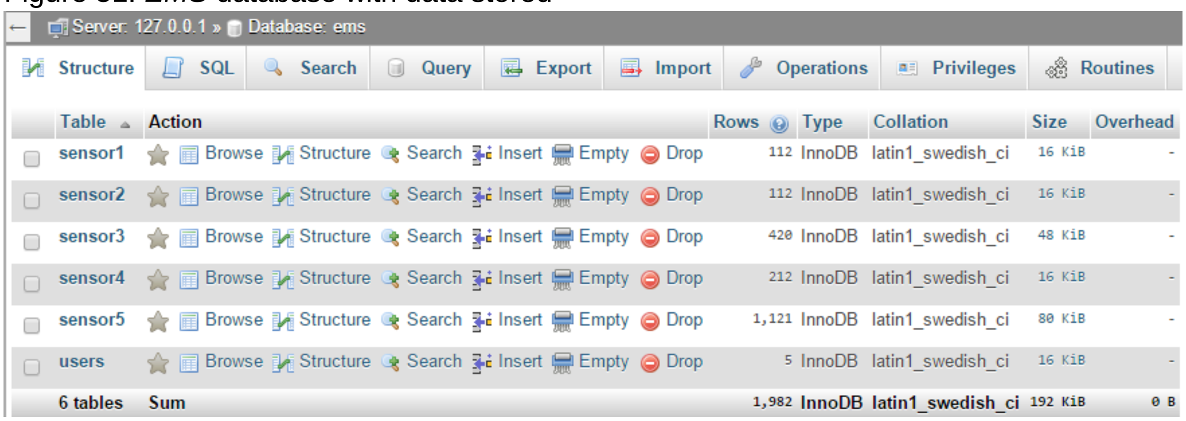
The description of the entire system begins with the proper selection of the sensor to monitor the behavior of an appliance. The kilowatts per hour or the current must not exceed the limits of the sensors. After being sure of the sensor selection, the appliance is connected to the sensor, and it is then plugged in the electrical network. Every 20 seconds, the sensor will send the data measured from the appliance to the server, which has already set to work. The ACS712 sensor transduces the amperes into millivolts, these millivolts are amplified, rectified and filtered and are converted into a digital data using the ADC of the ATMEGA 328P. The program of the microcontroller starts reading every 20 seconds the analog input, where the signal comes from, and using string sentences via serial, it communicates with the ESP8266 Wi-Fi module so it sends the data and establishes connection with a PHP file, via TCP connection. Now, the user can log in or sign up in the webpage so he can select the sensor, the range of time and monitor the behavior of the appliance.

9.1 DATABASE STORAGE VALIDATION

The following images prove that the data from the sensors was actually stored in each one of the tables, and the signed up information of the users as well, through the *phpMyAdmin* database manager.

The Figure 51 shows the tables of the *EMS* database (Energy Monitoring System), indicating the amount of registers stores by table, with a total of 1982 registered data.

Figure 51. *EMS* database with data stored



Server: 127.0.0.1 » Database: ems

Structure | SQL | Search | Query | Export | Import | Operations | Privileges | Routines

Table	Action	Rows	Type	Collation	Size	Overhead
sensor1	Browse Structure Search Insert Empty Drop	112	InnoDB	latin1_swedish_ci	16 KiB	-
sensor2	Browse Structure Search Insert Empty Drop	112	InnoDB	latin1_swedish_ci	16 KiB	-
sensor3	Browse Structure Search Insert Empty Drop	420	InnoDB	latin1_swedish_ci	48 KiB	-
sensor4	Browse Structure Search Insert Empty Drop	212	InnoDB	latin1_swedish_ci	16 KiB	-
sensor5	Browse Structure Search Insert Empty Drop	1,121	InnoDB	latin1_swedish_ci	80 KiB	-
users	Browse Structure Search Insert Empty Drop	5	InnoDB	latin1_swedish_ci	16 KiB	-
6 tables	Sum	1,982	InnoDB	latin1_swedish_ci	192 KiB	0 B

Source: The author

As an example of the data stored in one of the sensor's table, the Figure 52 displays the information obtained and later stored in the *sensor2* table, from the sensor that measured the current of the steam iron. Five columns, by order indicating the generated current, the energy consumed in that moment, the cost of the energy consumed in that instant of time, the time the data was stored and the bits regarding the microcontroller, so the calculation could be done. All these data prove the sensor was acquiring and sending the data in real-time.

Figure 52. *sensor2* table displaying data stored

current	kwh	price	time	bits
0	0	0	2016-01-29 20:20:08	0
0	0	0	2016-01-29 20:20:28	0
0	0	0	2016-01-29 20:20:48	0
0	0	0	2016-01-29 20:21:09	0
0	0	0	2016-01-29 20:21:29	0
0	0	0	2016-01-29 20:21:49	5
0	0	0	2016-01-29 20:22:09	6
0	0	0	2016-01-29 20:22:30	1
0	0	0	2016-01-29 20:22:50	0
0	0	0	2016-01-29 20:23:10	1
6.6896	0.00439239	1.8	2016-01-29 20:23:30	438
6.7172	0.00441051	1.80743	2016-01-29 20:23:51	440
6.6068	0.00433802	1.77772	2016-01-29 20:24:11	432
6.524	0.00428366	1.75544	2016-01-29 20:24:31	426
6.6896	0.00439239	1.8	2016-01-29 20:24:51	438
6.5516	0.00430178	1.76287	2016-01-29 20:25:12	428
6.5378	0.00429272	1.75916	2016-01-29 20:25:32	427
0	0	0	2016-01-29 20:25:53	3
6.6344	0.00435615	1.78515	2016-01-29 20:26:13	434
1.2946	0.000850034	0.348344	2016-01-29 20:26:33	62

Source: The author

Finally, the Figure 53 displays the information that some users signed up in the webpage to be able to access the monitoring system. The columns depicted are the username or nickname, the password, and a contact e-mail.

Figure 53. *users* table displaying data stored

Server: 127.0.0.1 » Database: ems » Table: users

Browse | Structure | SQL | Search | Insert | E

	user_id	username	password	email
Edit Copy Delete	1	nick1	1234	1@h.com
Edit Copy Delete	2	nick2	987654321	j@k.com
Edit Copy Delete	3	nick3	test	a@a.com
Edit Copy Delete	4	nick4	prueba1	k@y.com
Edit Copy Delete	5	nick5	lupe	l@f.com

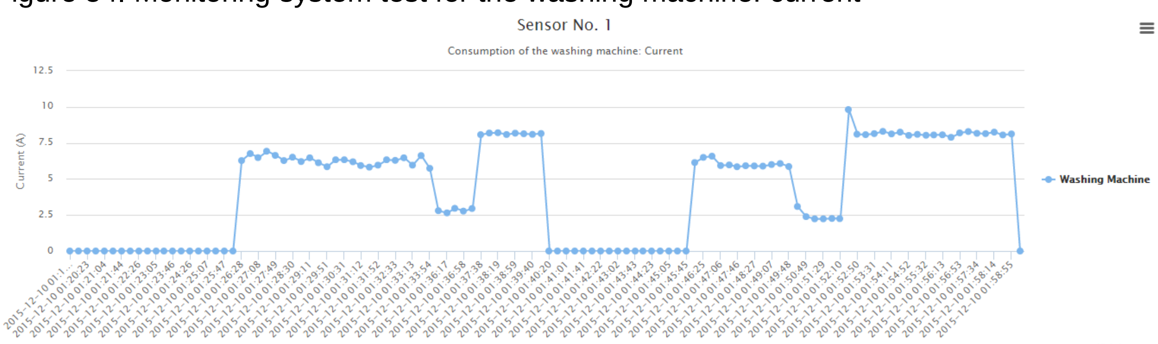
Check All *With selected:* Change Delete Export

Source: The author

9.2 WASHING MACHINE VALIDATION

The Figure 54 represents the current generated by the washing machine with medium load. The 20A version of the ACS712 current sensor was used. There is almost a total match between Figures 10 and 54, the main centrifuging is up from 7A to 5.5A approximately, later the current drops to 2,7A because of the change of stage (to pumping) and rises to 8,5A due to the spinning stage. The cycle repeats once again, reducing the time of the main centrifuging and increasing the spinning time. The cycle lasted 40 minutes to be completed, and the filling stage was taken as zero current, because the sensor is not able to measure low currents. This test was carried out while the test of the fluorescent lightbulb was in progress.

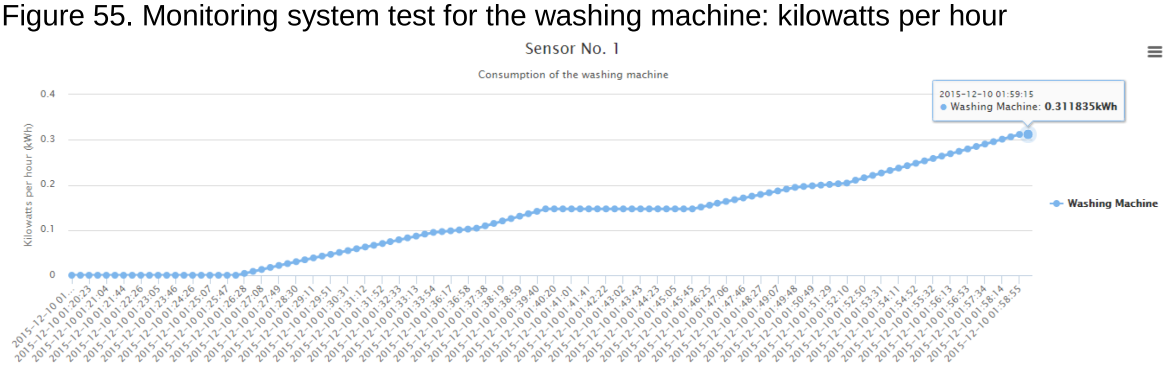
Figure 54. Monitoring system test for the washing machine: current



Source: The author

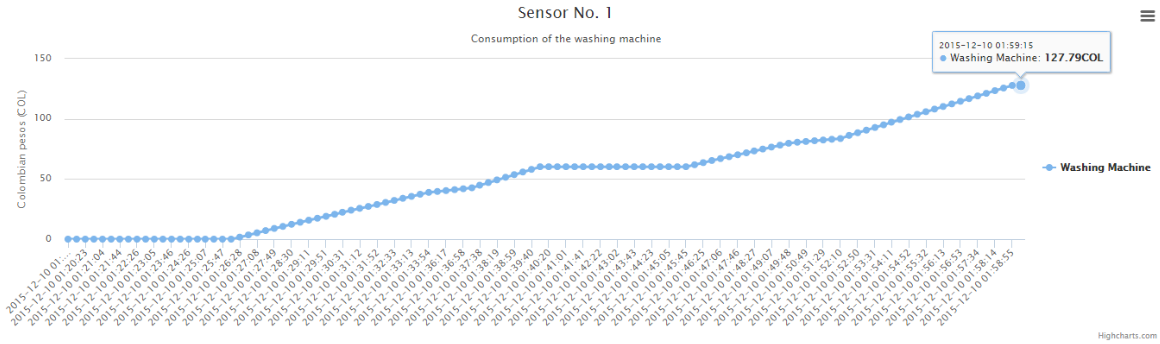
In addition, Figures 55 and 56 represents the cumulative sum, or the increase of the energy consumed and cost of consumption respectively. According to the monitoring system, the use of the washing machine with medium load consumes 0.31kWh and costs

Figure 55. Monitoring system test for the washing machine: kilowatts per hour



Source: The author

Figure 56. Monitoring system test for the washing machine: cost of consumption

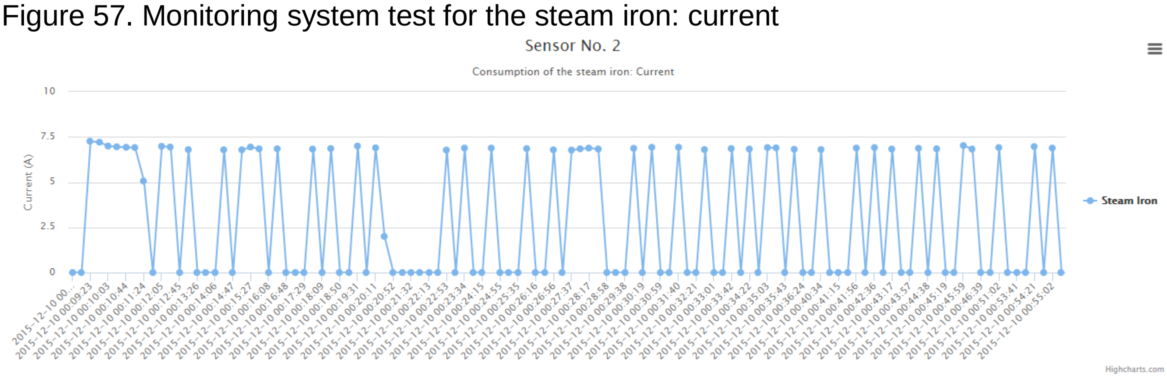


Source: The author

9.3 STEAM IRON VALIDATION

The current generated and reported by the monitoring system is shown in the Figure 57. The 20A version of the ACS712 was implemented to make the test. It is very clear the behavior of the steam iron, if it is compared with the Figure 16. There is a constant change in the current, rising up to 7A and dropping to 0A, meaning a temperature regulation of the steam iron, and the intervals between high and low states depend on the time the iron is on the clothing. This test took 46 minutes and 39 seconds. It is also evident, the constant value of the high state, being between 7A and 6.8A. This test was made while the fluorescent lightbulb's test was on too.

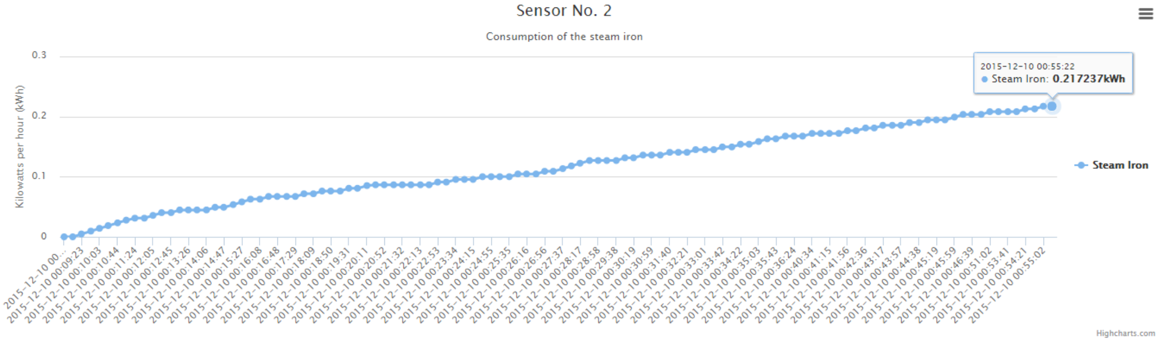
Figure 57. Monitoring system test for the steam iron: current



Source: The author

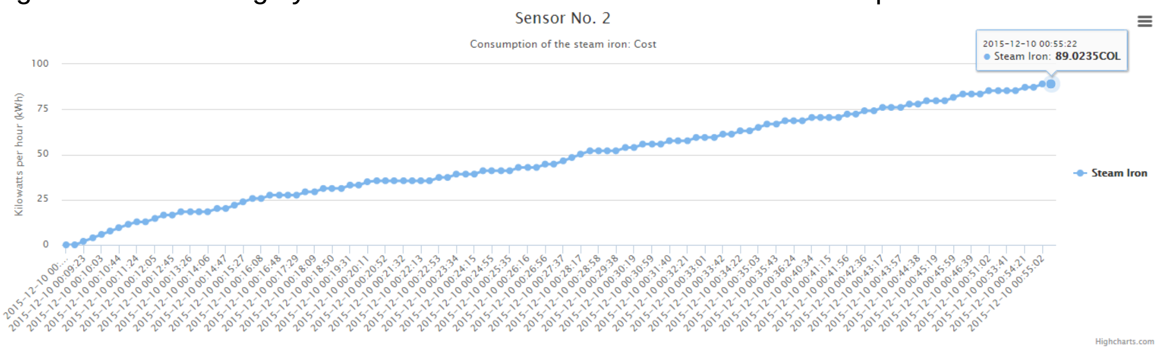
The Figure 58 shows the increasing consumption of power during the test, while the cost of the consumption can be appreciated in the Figure 59. The monitoring system suggests that the use of the steam iron during this test costed $89 COL and 0.21kWh were consumed.

Figure 58. Monitoring system test for the steam iron: kilowatts per hour



Source: The author

Figure 59. Monitoring system test for the steam iron: cost of consumption

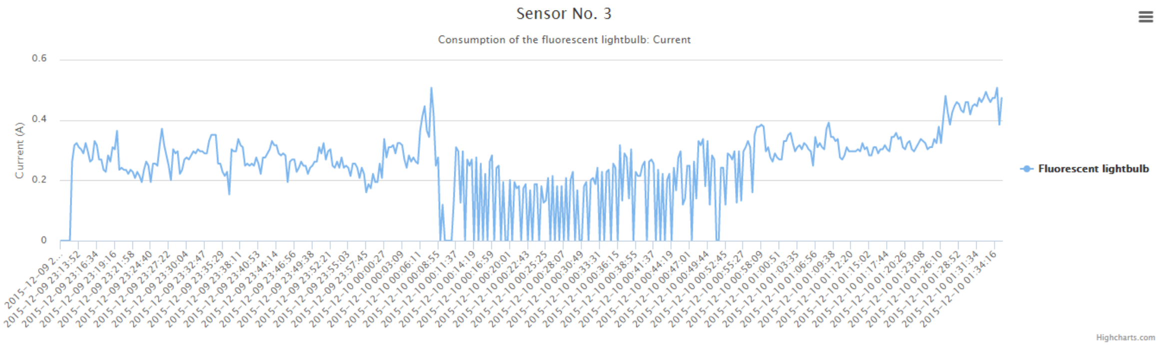


Source: The author

9.4 FLUORESCENT LIGHTBULB VALIDATION

The Figure 60 shows the data of current obtained from the 5A sensor, taken during 2 hours and 24 minutes. Having into account that the ACS712 current sensor is not good at measuring low currents, and that the chosen lightbulb consumes up to 0,3kWh, that is to say around 250mA of generated current. The Figure 60 evidences the bad quality of measuring low currents, having big fluctuations and knowing that the consumption of a fluorescent lightbulb is almost constant and it tends to drop to 200mA, but the graphic below shows a variation from 153mA to 507mA.

Figure 60. Monitoring system test for the fluorescent lightbulb: current

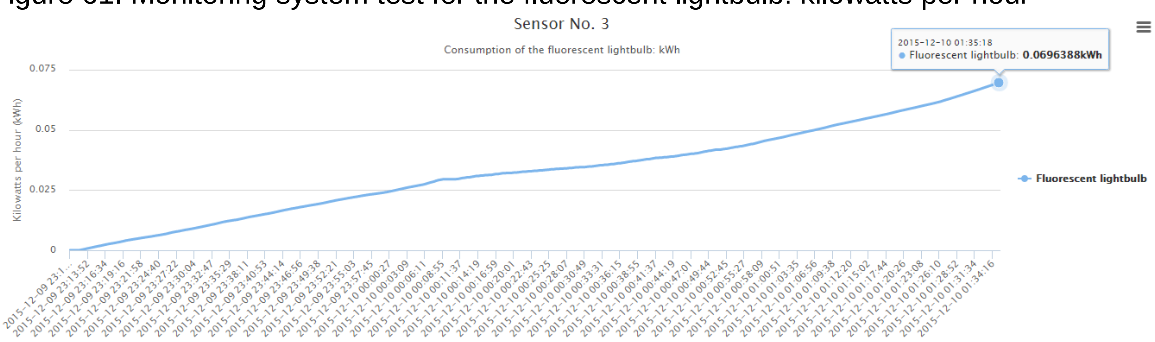


Source: The author

While this test was in progress, the test of the steam iron started, provoking a bad acquisition of data during the test, dropping and fluctuating from 0A to 0,31A, and it can also be appreciated in the Figure 60, from 00h11 to 00h55 approximately. The test of the washing machine started at 01h19, and the test of the lightbulb was also affected, but in a different way, increasing the lectures from 0.31A to 0.51A, and it can be seen at the final part of the graphic.

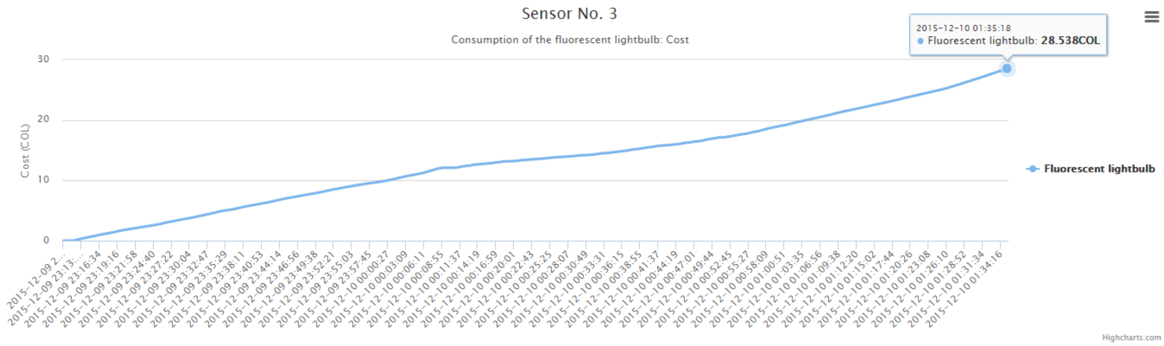
The Figure 61 shows the increasing consumption of power of the fluorescent lightbulb during the test, while the cost of the consumption can be appreciated in the Figure 62. The monitoring system registers that the use of a 20W fluorescent lightbulb during this test costed $28 COL and 0.07kWh were consumed.

Figure 61. Monitoring system test for the fluorescent lightbulb: kilowatts per hour



Source: The author

Figure 62. Monitoring system test for the fluorescent lightbulb: cost of consumption

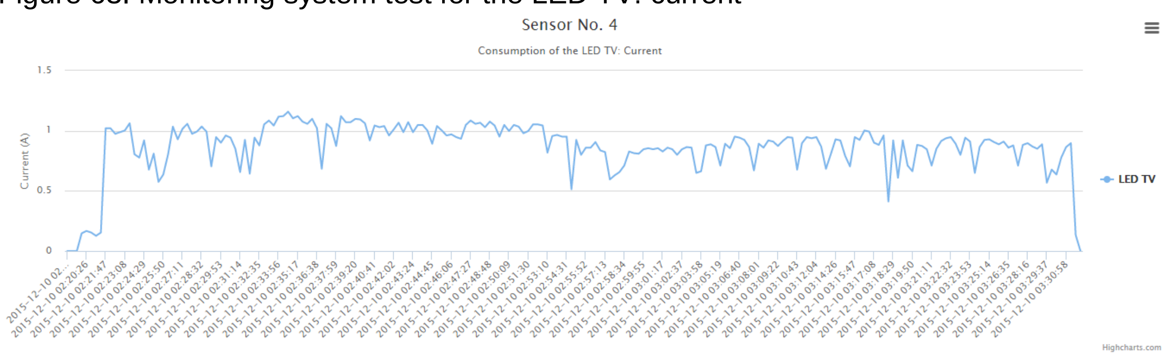


Source: The author

9.5 LED TV VALIDATION

The version of the ACS712 sensor to do the validation was the 5A. The Figure 63 shows the current generated by the LED TV during 1h and 12 minutes. The chart presents a fluctuation between 0,411A as minimum and 1,158A as maximum, and this variation depends only on the quality of image set in the TV and the different colors the LEDs project.

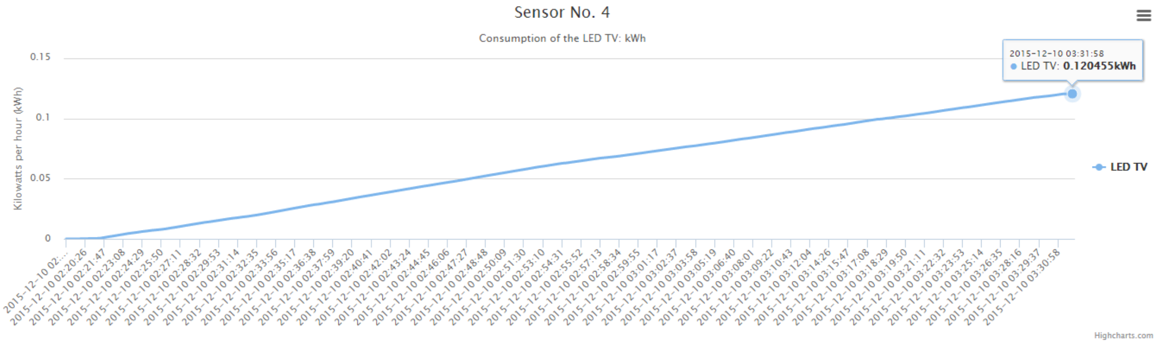
Figure 63. Monitoring system test for the LED TV: current



Source: The author

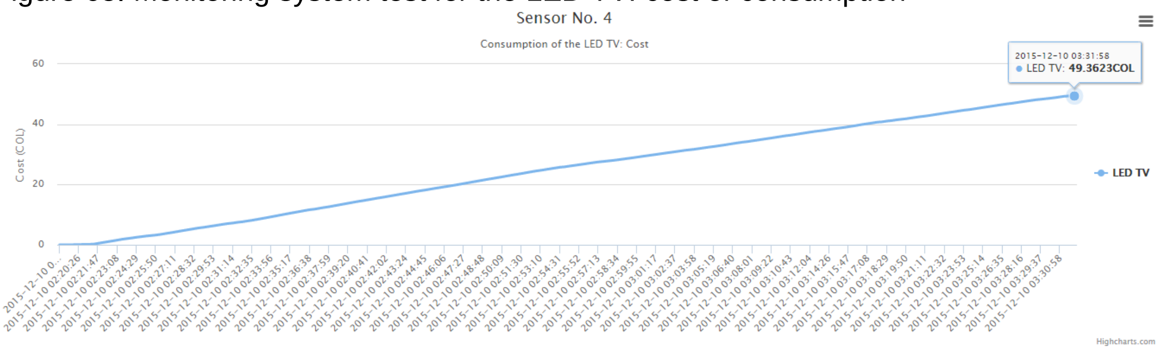
The Figure 64 shows the increasing consumption of power of the LED TV during the test, while the cost of the consumption can be appreciated in the Figure 65. The monitoring system depicts that the use of this LED TV during this test costed $49COL and 0.120kWh were consumed.

Figure 64. Monitoring system test for the LED TV: kilowatts per hour



Source: The author

Figure 65. Monitoring system test for the LED TV: cost of consumption

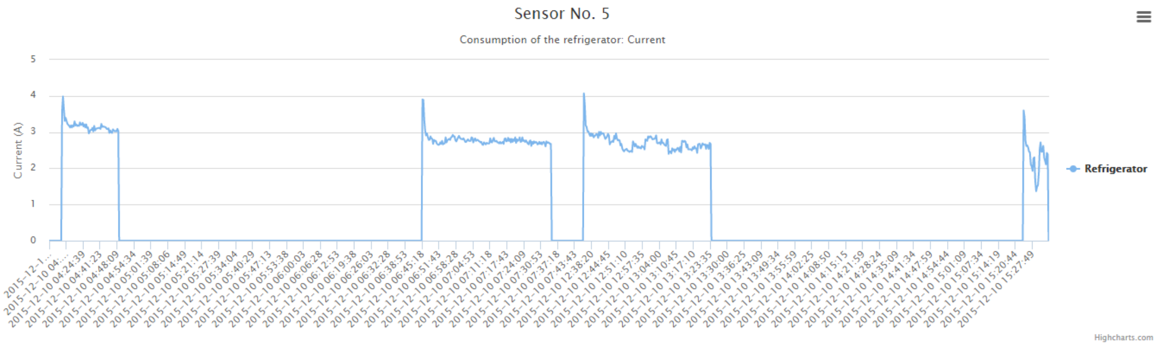


Source: The author

9.6 REFRIGERATOR VALIDATION

The version of the ACS712 sensor appropriated to monitor the refrigerator is the 5A, but according to the data depicted in the Figure 14, there is a starting current of 14A, that might damage the sensor, so it was decided to implement the 20A version for the sensor, to prevent any damage. The Figure 66 shows the current generated by the refrigerator in two lapses of time: from 04h11 to 07h46 and from 12h34 to 15h36. In both cases, there is a match between the data portrayed in the Figure 14, an initial current of approximately 3,8A and it decreases constantly to 2,5A. The final part of the chart shows a collapse of the current to 1,36A due to the use of a microwave that was next to the sensor, occasioning an interference for the acquisition of data.

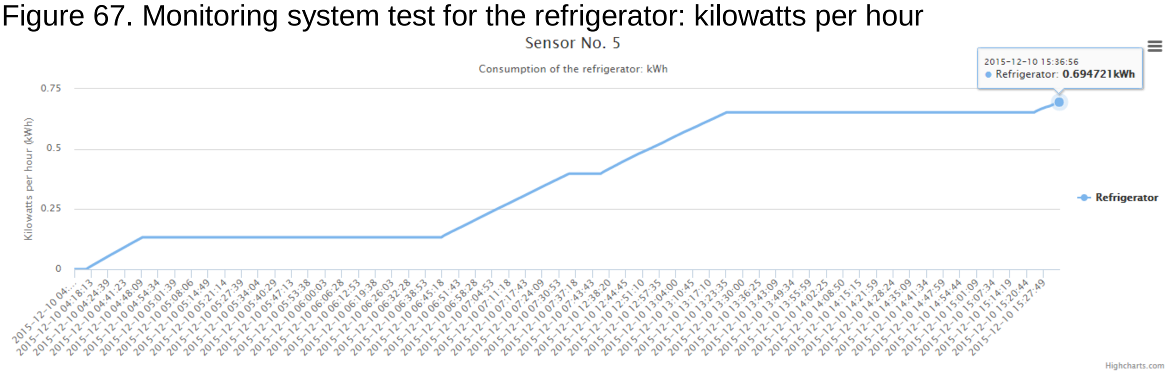
Figure 66. Monitoring system test for the refrigerator: current



Source: The author

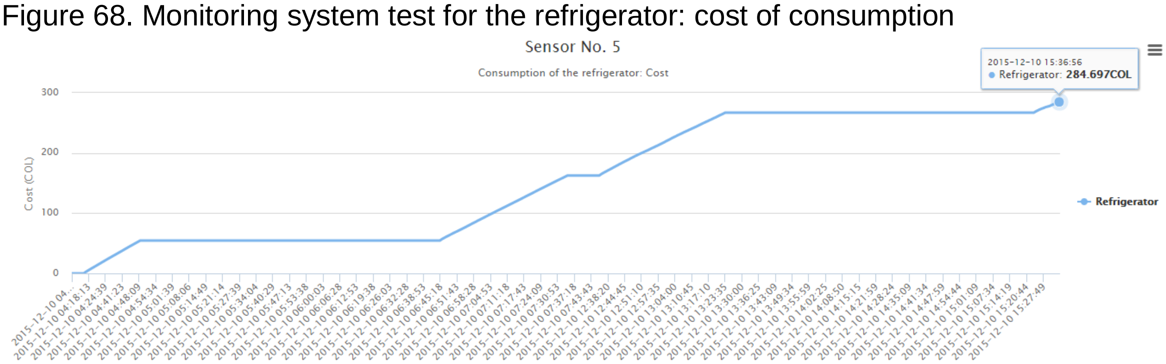
The Figure 67 evidences the increasing consumption of power of the refrigerator during 5 hours and 37 minutes that took the test, while the cost of the consumption can be seen in the Figure 68. The monitoring system depicts that the use of this refrigerator during this test costed $284COL and 0.694kWh were consumed.

Figure 67. Monitoring system test for the refrigerator: kilowatts per hour



Source: The author

Figure 68. Monitoring system test for the refrigerator: cost of consumption



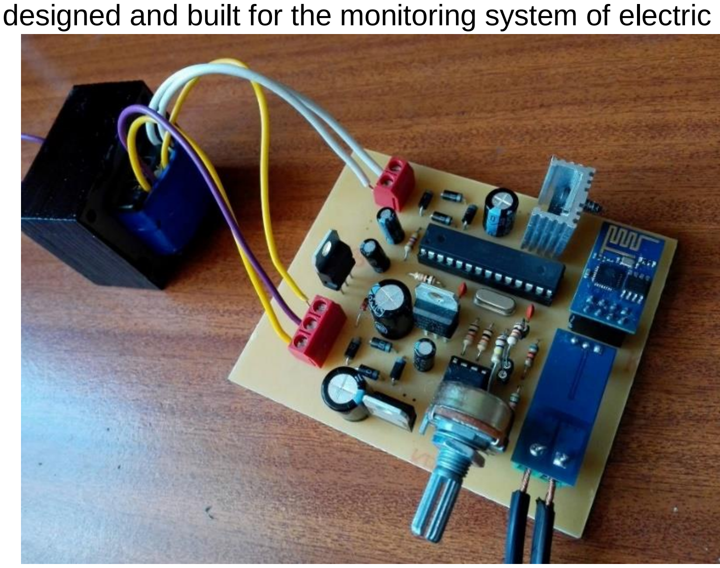
Source: The author

It is important to remark that the sporadic malfunctioning or stop of the sensors when sending the data is random, and this problem has not been identified, but it is possible to hypothesize that the intensity of the Wi-Fi is not good or the power source used to supply the entire circuit is failing somehow. These hypotheses are based on the bad historical review that the Wi-Fi network used has and the discovery of some harmonics and grounding troubles that forced the change of the transformer, previously explained in the Section 6.1. Also, no power factor was taken into account to calculate the consumption of the appliances, so the sensors only measure the current to obtain the energy consumed, as the W=V*I formula, obtaining the active or real power, supposing that all the loads and appliances are resistive.

Due to the little variation when the ESP8266 is sending the data, the uncertainty of the real value for the 5A sensor is about ±100mA, while the 20A goes around ±500mA, according to the characterization of the sensors and the splitting of the slope in several ranges, so the measure can approach to the desired and real data.

Finally, a photograph of one of the sensors is presented in the Figure 69, and the electric plan in the Appendix J.

Figure 69. Sensor designed and built for the monitoring system of electric energy



Source: The author

10 CONCLUSIONS

- The monitoring system satisfies the main objective of making a tracing of the behavior of some appliances inside a house, showing graphically the instant current generated while connected, the cumulated energy consumed and the cost in Colombian pesos of the energy consumed so far, in real-time.

- The monitoring system helps the user to know the behavior and consumption of his appliances, allowing him to take actions to reduce his impact to the environment and the bill's cost.

- The choice of implementing the Wi-Fi technology to transmit the data to the database is because of the advantages of connecting multiples devices to one network, and also taking advantage of the existing Wi-Fi networks that nowadays every single house needs to connect to the Internet, putting away the Bluetooth technology, that does not allow multiple connections or the RFID, being a bit more expensive.

- The comparison between the charts from the Chapter 5 (analysis of the chosen appliances) and Chapter 8 (monitoring system tested and implemented) concludes that there is a better accuracy of the data using the data shown only by the microcontroller, using the Arduino Serial Monitor, because the sampling time is shorter, and can be set even at every second, but the sensors would not be remotes. Otherwise, using the Wi-Fi module ESP8266, the minimum sampling time is 7 seconds, due to the instructions that need to be sent according to the communication protocol.

- There is an undesirable variation of the signal in the circuit while the Wi-Fi module ESP8266 executes an instruction. The solution was to delay the intervals for the taking of samples, so the signal has the chance and the time to stabilize itself and after the signal is assigned to the variable, the ESP8266 will not interfere in the accuracy of the data.

- The characterization of the sensors and the charts obtained while measuring the consumption nodes conclude that both sensors are not recommended to measure low currents (from 0A to 0,5A for the 5A version and from 0A to 1,5 for the 20A version), or devices that consume up to 50W per hour.

- Different appliances were measured to demonstrate the functionality of both versions of the ACS712 (5A and 20A), and allowed to represent the behavior of their current in real time.

- The 5A sensor designed and built is capable of measure from 0A to 5,036A according to its characterization, while the 20A sensor was set to measure up to 12,94A because there is no appliance with such consumption, so it could be set with a lower top to improve the resolution of data. Either way, it can be set to measure 20A just by adjusting the gain in the differential amplifier and changing the formula in the PHP file that fills the tables of the database.

- Both sensors present a stop in their operation, which occurs randomly after certain period of time.

- The HMI, in this case the webpage, has a friendly environment with the user, and it is easy to navigate. This webpage allows the user to register and access the monitoring system to monitor each behavior of any sensor independently.

- The webpage allows the user to obtain reports from the range of data selected, and PNG or PDF images as well.

RECOMMENDATIONS
IMPORTANT SAFETY INSTRUCTIONS

1) Read these instructions.
2) Keep these instructions.
3) Heed all warnings.
4) Follow all instructions.
5) Do not use this device near water.
6) Do not open the sensor. Risk of electric shock.
7) Do not install near any heat sources such as radiators, heat registers, stoves, or other apparatus (including amplifiers) that produce heat.
8) Unplug this device during lighting storms or when unused for long periods of time.
9) Contact the manufacturer for further information or any doubt.

WARNING: To reduce the risk of fire or electric shock, do not expose this device to rain or moisture. The device must never be exposed to dripping, splashing, or spilling liquids of any kind.

OUTDOOR USE: Do not install this device outdoors. The sensor should not be exposed to rain or direct sunlight in order to avoid damage and possible fire or electric shock.

MAGNETIC INFLUENCE: This device contains a transducer that is very sensitive to magnetic fields. Keep any items susceptible to magnetic fields away from the sensor. Electro-magnetic radiation emitted from optional equipment installed too close to the sensor may cause variation and malfunction of the measured data.

Before using any sensor, check the label of the appliance you wish to measure, in order to select what version of the sensor must be used. If the appliance indicates in the label less than 5A or 550W to 600W, use the 5A sensor, otherwise, the 20A is the required.

If the blue LED of the Wi-Fi module does not blink, or there is no new information while the sensor is running, unplug and plug the sensor again to the electrical network.

IMPLEMENTATION COSTS

In the Table 19, the approximate costs of the entire system is presented for it to be implemented in a regular house, assuming that it counts with a router and Internet service.

Table 19. Implementation costs

Item	Quantity	Price		Description
		Unit	Total	
Transformer	5	$22.000	$110.000	Power supply for the sensors
PCB	5	$10.000	$50.000	Board to weld the elements
Tin solder	1	$12.000	$12.000	Mount the elements on the PCB
ESP8266 Module	5	$15.000	$75.000	Data transmission
ACS712 Sensor	5	$15.000	$75.000	Sensor to measure the current
ATMEGA328P	5	$8.000	$40.000	Microcontroller to send the commands
Voltage regulator to 9V and 5V	10	$800	$8.000	Regulator to the electronic items
Voltage regulator to 3,3V	5	$2.000	$10.000	Regulator to the ESP8266 module
AC Power plugs	10	$3.000	$30.000	To connect the appliance and the electric network
Electronic elements	-	-	$35.000	Resistors, capacitors, diodes, terminal blocks, bases, heat sinks, push-buttons, potentiometer, OP AMP, quarz
PMMA boxes	5	$25.000	$125.000	Box for the sensor
Computer	1	$1.400.000	$1.400.000	Runs the server, compatible with XAMPP
		Total	$1.970.000	
Source: The Author				

BIBLIOGRAPHY

Adobe. (2015). *Adobe*. Retrieved from http://www.adobe.com/products/dreamweaver.html

Allegro. (2012, November 16). *Allegro Micro.* Retrieved from http://www.allegromicro.com/~/media/Files/Datasheets/ACS712-Datasheet.ashx?la=en.

Ambler, S. W. (2014). *Agile Modeling*. Retrieved from http://www.agilemodeling.com/artifacts/useCaseDiagram.htm

Arduino. (2015). Retrieved from Arduino: https://www.arduino.cc

Basic Electronic Tutorials. (2015, December 1). Retrieved from Basic Electronic Tutorials: http://www.electronics-tutorials.ws/opamp/opamp_5.html

Carballar, J. (2004). *Wi-Fi: cómo construir una red inalámbrica.* Ra-Ma.

CODENSA. (2015). *Codensa.* Retrieved from https://www.codensa.com.co/empresas/guias/indicadores-energeticos/tarifas

Comment Ça Marche. (2015, December). Retrieved from CCM: http://www.commentcamarche.net/contents/1083-systeme-d-information

cplusplus.com. (2015). *cplusplus.com*. Retrieved from http://www.cplusplus.com/doc/tutorial/introduction/

Cruz, Y. (2013). *Diseño e implementación de un sistema para el monitoreo y control de puntos de consumo de energía eléctrica, utilizando dispositivos móviles y tecnología Bluetooth.* Bogotá: Tesis.

ECLAC. (2008, March). *Comisión Económica para América Latina y el Caribe*. Retrieved from http://www.cepal.org/colombia/noticias/documentosdetrabajo/0/35290/EstEco3511-03-_07-G-ES.pdf

Elmasri, R., & Navathe, S. (2002). *Fundamentos de bases de datos.* Madrid: Pearson Education.

Enginner's Garage. (2012). *Enginner's Garage*. Retrieved from http://www.engineersgarage.com/articles/what-is-wifi-technology

Erwin, Z. (2011, May 18). *Qwhatis*. Retrieved from http://www.qwhatis.com/what-is-xampp/

Espressif Systems. (2013, October 2013). *nurdspace.* Retrieved from https://nurdspace.nl/images/e/e0/ESP8266_Specifications_English.pdf

Geek Factory. (2015). *GeekFactory.com*. Retrieved from http://www.geekfactory.mx/tienda/sensores/modulo-con-sensor-de-corriente-acs712-20-a/

Home Energy Saver. (2015). *HES*. Retrieved from http://hes-documentation.lbl.gov/calculation-methodology/calculation-of-energy-consumption/major-appliances/miscellaneous-equipment-energy-consumption/default-energy-consumption-of-mels

Loflin, L. (n.d.). *Bristol Watch*. Retrieved from http://www.bristolwatch.com/hall_effect/ac_hall_effect.htm

Martínez Peralta, J. D. (2013). *Sistema de monitoreo y adquisición de datos para un vehículo de distribución de fertilizantes químicos.*

Martínez Rodríguez, J. D., & Moreno Vivas, I. G. (2010). *Diseño de un sistema domótico para la gestión de confort de la sala de estar de un apartamento.* Bogotá.

Ministry of Mines and Energy. (2007). *Unidad de Planeación Minero Energética.* Bogotá, D.C.: Ministerio de Minas y Energía. Retrieved from http://www.upme.gov.co/Docs/balance_energetico_2006.pdf

Ministry of Mines and Energy. (2011). *Ministerio de Minas y Energía.* Retrieved from http://www.minminas.gov.co/minminas/downloads/UserFiles/File/Memorias/Memorias_2011/05-ENERGIA.pdf

MySQL. (2015). *MySQL*. Retrieved from https://dev.mysql.com/doc/refman/5.7/en/what-is-mysql.html

Object Management Group. (2015, June 24). Retrieved from OMG: http://www.omg.org/gettingstarted/what_is_uml.htm

Patiño López, J. I., & Medellín Guzmán, O. J. (2014). *IMPLEMENTACIÓN DE UNA RED DE SENSORES INTELIGENTES MEDIANTE COMUNICACIÓN INALÁMBRICA, PARA REDUCIR EL CONSUMO DE ENERGÍA.* Bogotá: Tesis.

Pridopia. (n.d.). Retrieved from Pridopia: http://www.pridopia.co.uk/pi-doc/ESP8266ATCommandsSet.pdf

RapidTables. (2015). *RapidTables*. Retrieved from http://www.rapidtables.com/electric/kWh.htm

RapidTables. (2015). *RapidTables.com*. Retrieved from http://www.rapidtables.com/calc/electric/energy-consumption-calculator.htm

Santos Rozo, G. A., & Aguirre Luna, A. A. (2009). *Diseño y modelado de un sistema para el control domótico por medio de un teléfono celular vía Bluetooth, WAP y mensajes de texto.* Bogotá: Tesis.

Secretaría General de la Alcaldía de Bogotá. (1994, 11 July). *Alcaldía de Bogotá*. Retrieved from http://www.alcaldiabogota.gov.co/sisjur/normas/Norma1.jsp?i=2752

Seeed. (2015). *Seeed.cc*. Retrieved from http://www.seeedstudio.com/depot/WiFi-Serial-Transceiver-Module-w-ESP8266-p-1994.html

Silberschatz, Korth, & Sudarshan. (2007). *Fundamentos de diseño de bases de datos.* Madrid: McGraw-Hill.

Sistema Único de Información de Servicios Públicos. (2015, December 4). *Sistema Único de Información de Servicios Públicos.* Retrieved from SUI: http://www.sui.gov.co/SUIAuth/portada.jsp?servicioPortada=4

Smart Home. (2015). *SmartHome*. Retrieved from http://www.smarthome.com/sc-what-is-home-automation

Study. (2015). *Study.com*. Retrieved from http://study.com/academy/lesson/hypertext-markup-language-software-to-create-web-pages.html

TechTarget. (2015). *whatis.techtarget.com*. Retrieved from http://whatis.techtarget.com/definition/server

The PHP Group. (2015). *php.net*. Retrieved from http://php.net/manual/en/intro-whatis.php

The World Bank. (2014). Retrieved from The World Bank: http://wdi.worldbank.org/table/3.8

The World Bank. (2014, September 28). *The World Bank*. Retrieved from http://data.worldbank.org/indicator/EN.ATM.CO2E.KT/countries/1W-CO?display=graph

W3 Schools. (2015). *W3 Schools*. Retrieved from W3 Schools: http://www.w3schools.com/css/default.asp

W3 Schools. (2015). *W3 Schools*. Retrieved from http://www.w3schools.com/js/

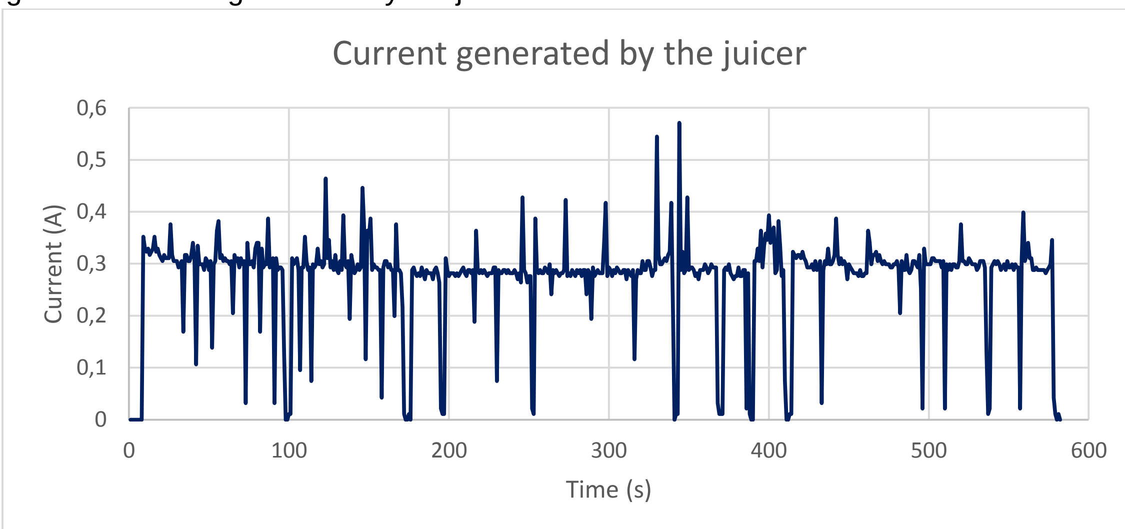
Williams, A. B. (1988). *Amplificadores operacionales: teoría y sus aplicaciones.* Mexico: McGraw-Hill.

Z. Cihan, T., M. Amac, G., & Melodia, T. (2010, November 2). *Northeastern University.* Retrieved from http://www.ece.neu.edu: http://www.ece.neu.edu/wineslab/papers/tinyEARS_buildsys_finalb.pdf

APPENDIX A
CONSUMPTION OF A JUICER

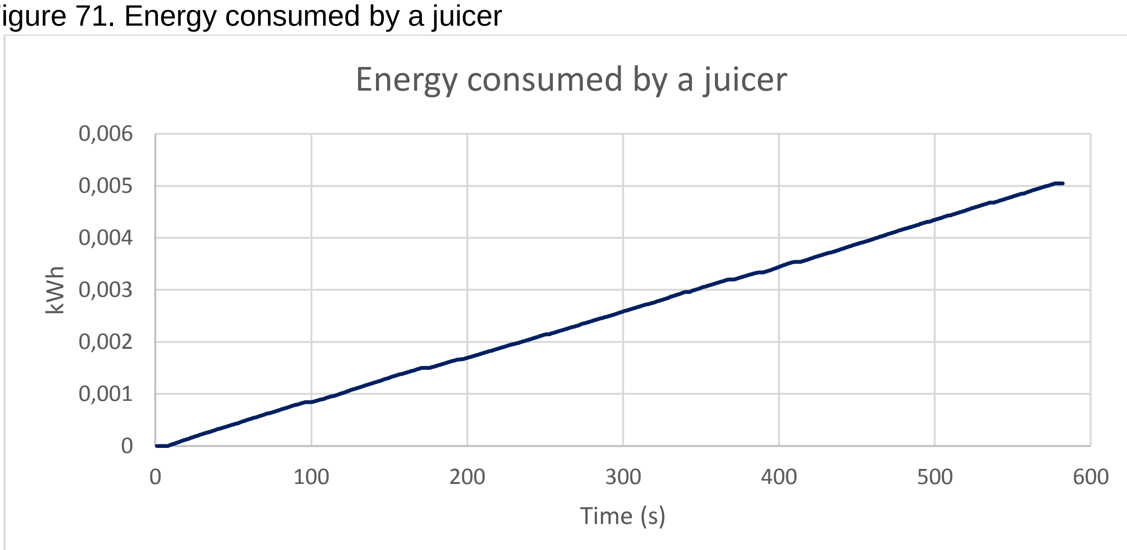
The juicer that was analyzed is not brand new, so it was unable to identify its manufacturer. It works at 120VAC, 50 to 60Hz and consumes 30Wh. In the Figure 70 can be seen the current generated while juicing four oranges. The values that are closed to zero show the moment where the juicer was not working, and it can be concluded that its average generated current is 300mA. Also in Figure 71 there is the increase of the energy consumed, being 31,2Wh according to the data collected.

Figure 70. Current generated by the juicer



Source: The author

Figure 71. Energy consumed by a juicer

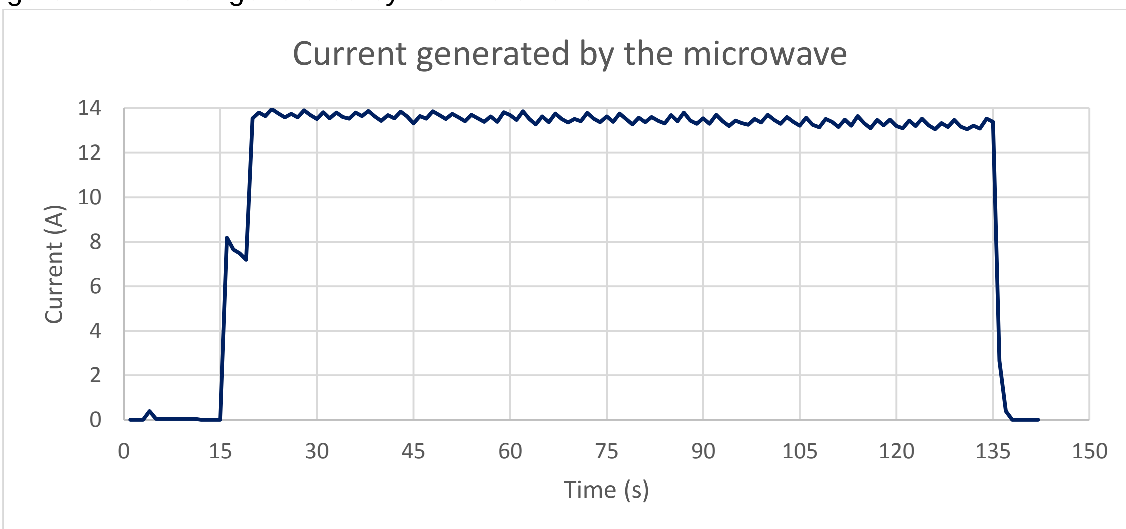


Source: The author

APPENDIX B
CONSUMPTION OF A MICROWAVE

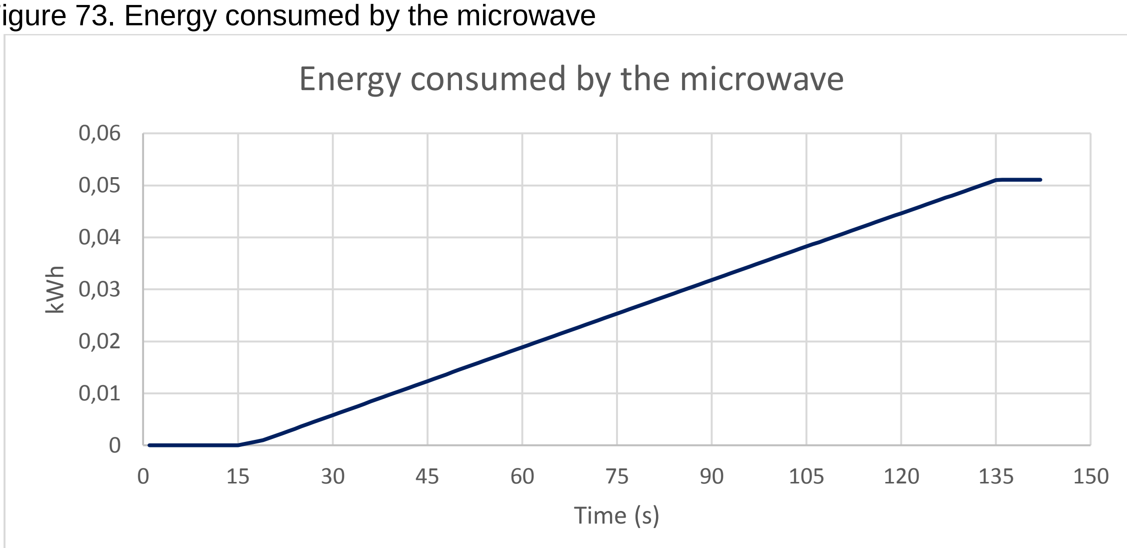
The Electrolux microwave, model EMX171D1PW, with capacity of 17L, that runs at 120VAC and 60Hz, with input power of 1050W and output of 750W, was measured. In the Figure 72, the maximum current at the beginning, starts to drop but not so much, until the set time is over, to warm a cup of coffee. In the Figure 73, the rise of the consumed power can be appreciated, being 1,29kWh according to the data collected.

Figure 72. Current generated by the microwave



Source: The author

Figure 73. Energy consumed by the microwave



Source: The author

APPENDIX C
CONSUMPTION OF A BLENDER

The Osterizer blender, *Imperial Pulse-Matic* model, which works at 120VC, 25 to 60Hz and consumes 375Wh at maximum. This blender counts with seven modes: chop, grate, grind, stir, puree, whip, mix, blend, frappe and liquefy. For the taking of samples, every mode was tested few seconds with no load, so the variation of the current generated by each one could be seen in the Figure 74. The Figure 75 shows a stepped graph indicating that the blender was running in intervals of time, consuming 2,74Wh according to the data collected.

Figure 74. Current generated by the blender

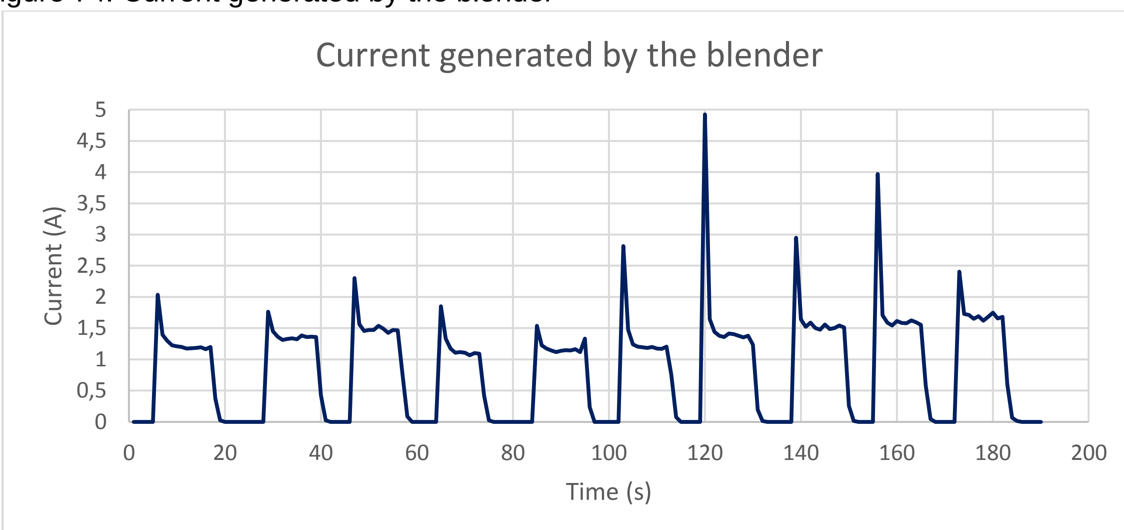
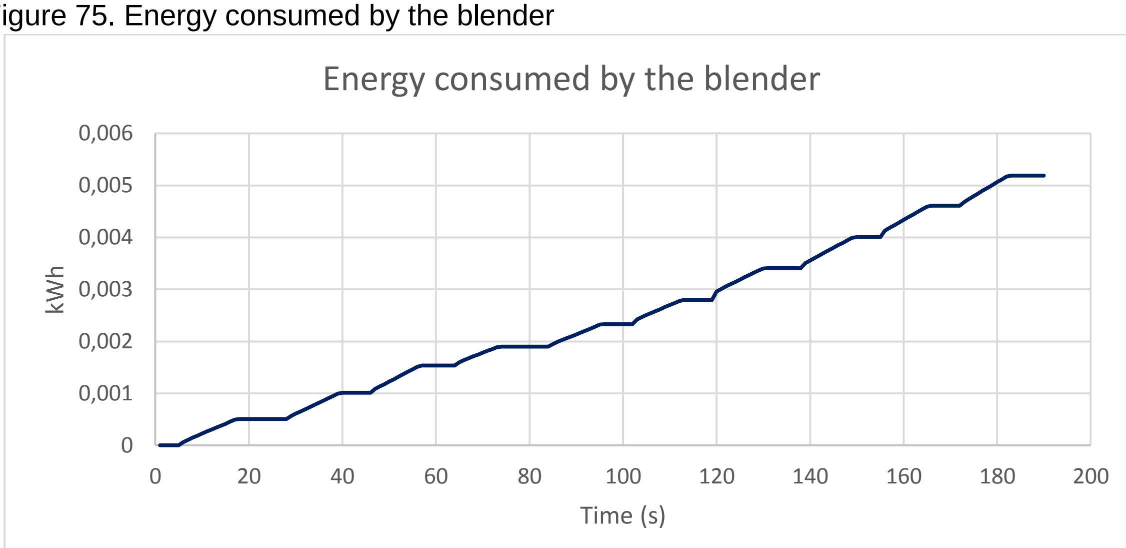


Figure 75. Energy consumed by the blender

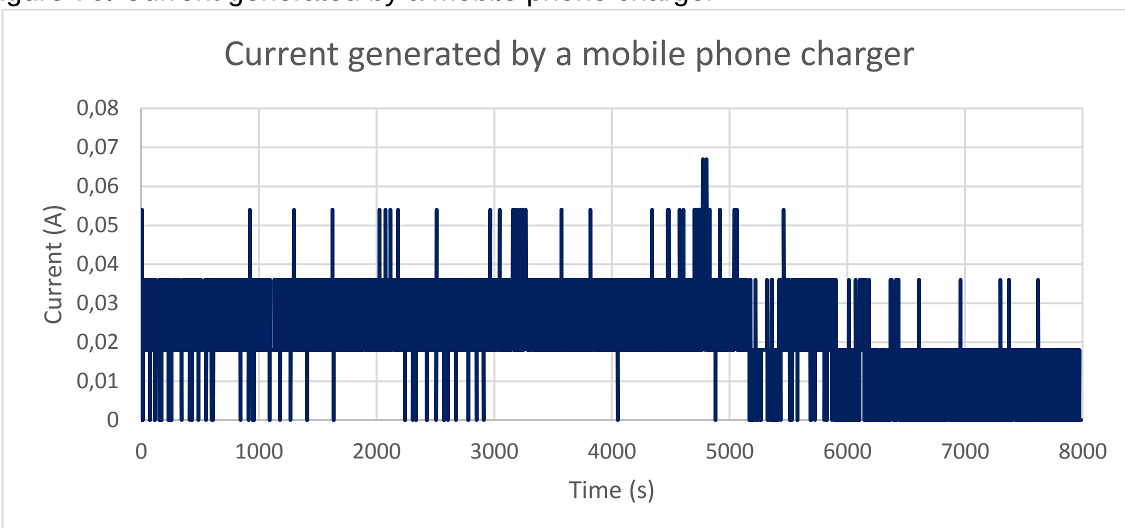


Source: The author

APPENDIX D
CONSUMPTION OF A MOBILE PHONE CHARGER

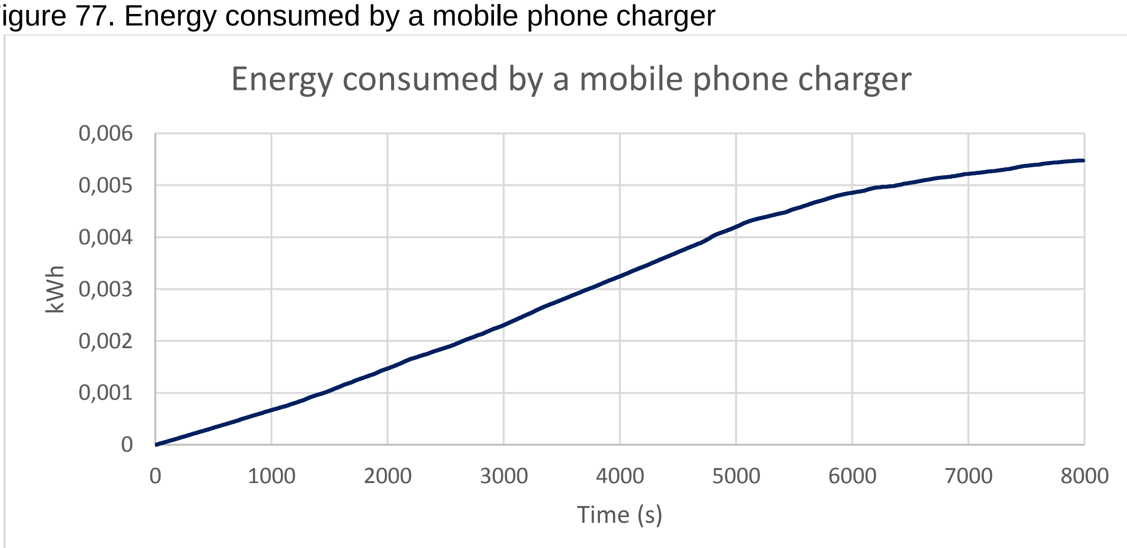
The Samsung mobile phone charger, model ETA3U30JBS, works from 100 to 240V, 50 to 60Hz and 0,15A, being In the Figure 76 the current generated can be appreciated, where the maximum current registered was 65mA approximately. As it was told before, the sensor is not recommended to be used with appliances or elements of low consumption. Nevertheless, its graphic of kilowatt consumption can be appreciated in the Figure 77, being 121,5Wh of consumption.

Figure 76. Current generated by a mobile phone charger



Source: The author

Figure 77. Energy consumed by a mobile phone charger

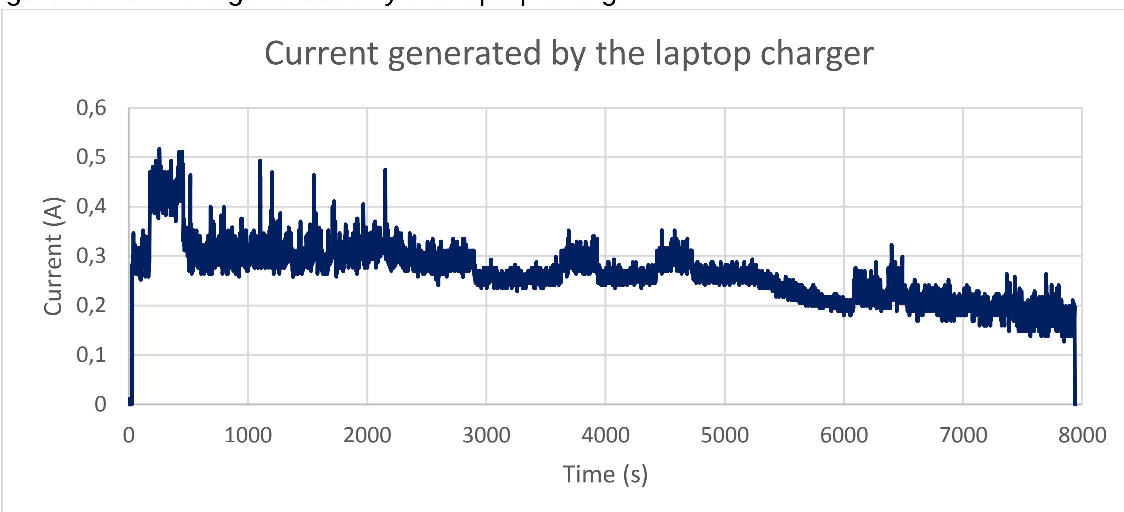


Source: The author

APPENDIX E
CONSUMPTION OF A LAPTOP CHARGER

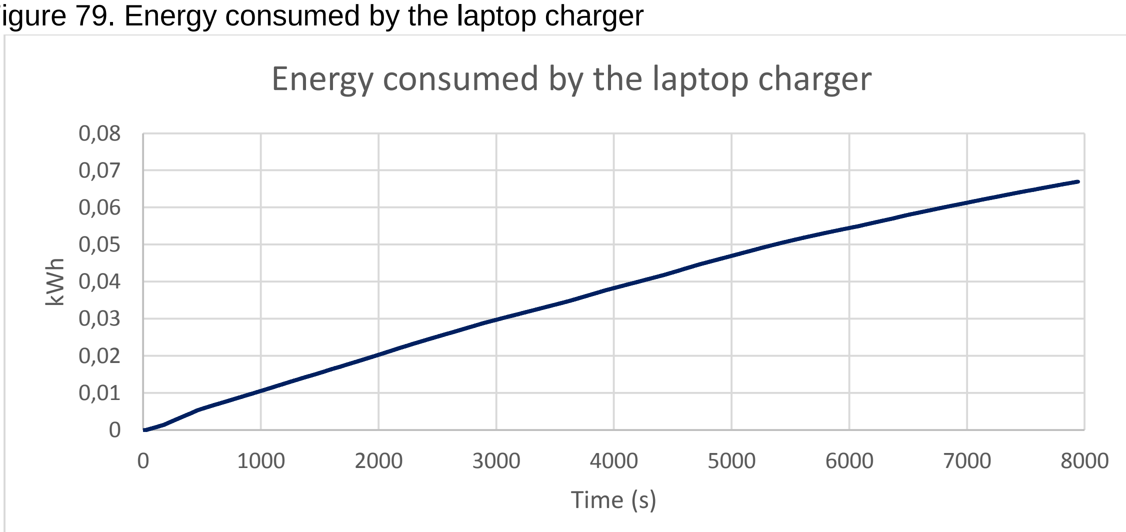
The ASUS laptop charger, model ADP-90YD B, works from 100 to 240VAC, at 50 to 60Hz, and generates 1,5A, that is to say 0,18kWh. As it can be seen in the Figure 78, the maximum current generated by the laptop charger is 0,53A. This current depends on the way the laptop is been used at the moment. It decreases as the time passes by, meaning that the laptop is almost done with a 100% charge. In the Figure 79, the power consumption shows a rising, resulting a consumption of 0,147kWh according to the collected data.

Figure 78. Current generated by the laptop charger



Source: The author

Figure 79. Energy consumed by the laptop charger

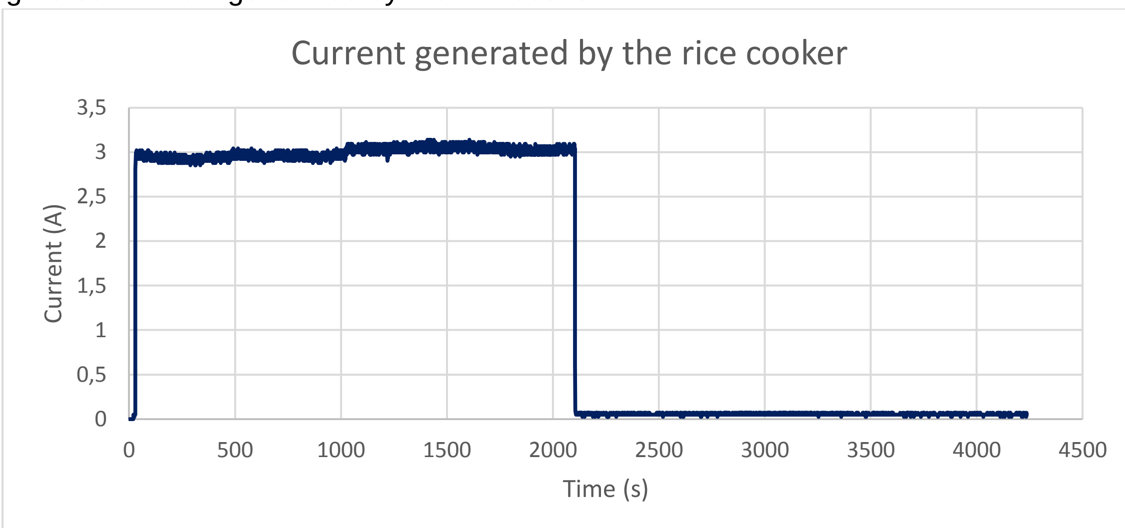


Source: The author

APPENDIX F
CONSUMPTION OF A RICE COOKER

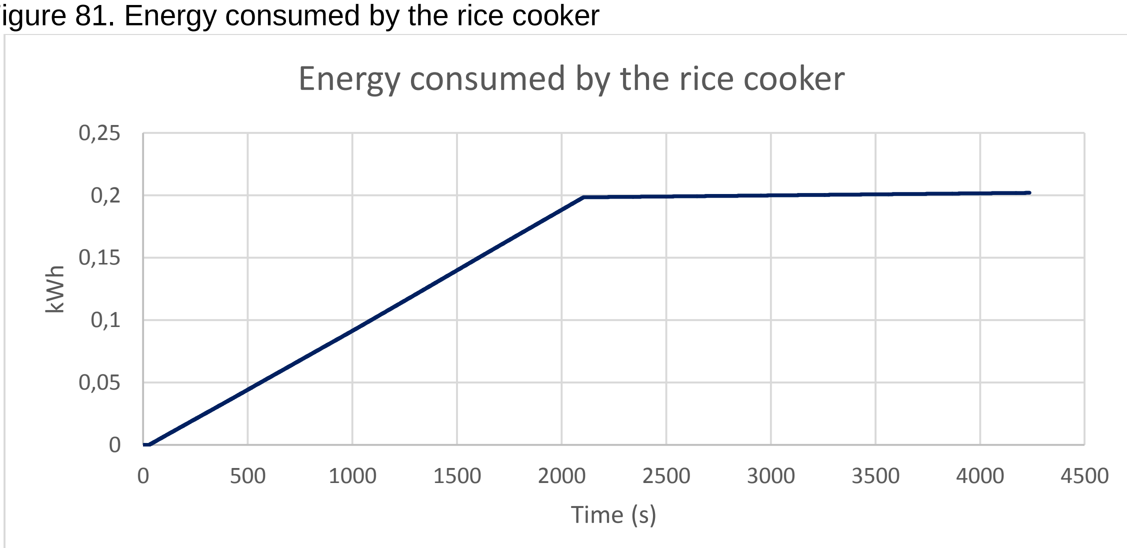
The Universal rice cooker, with no identifiable model, runs from 110 to 120VAC, 60Hz and consumes 500Wh. In the Figure 80, the behavior of the rice cooker can be observed. It requires 3A and almost 2100 seconds to the rice to be ready to eat. After that, it can be appreciated that there is a minimum current, approximately 48mA that keeps the rice warmed. The consumption of power can be seen in the Figure 81, being 0,201kWh.

Figure 80. Current generated by the rice cooker



Source: The author

Figure 81. Energy consumed by the rice cooker

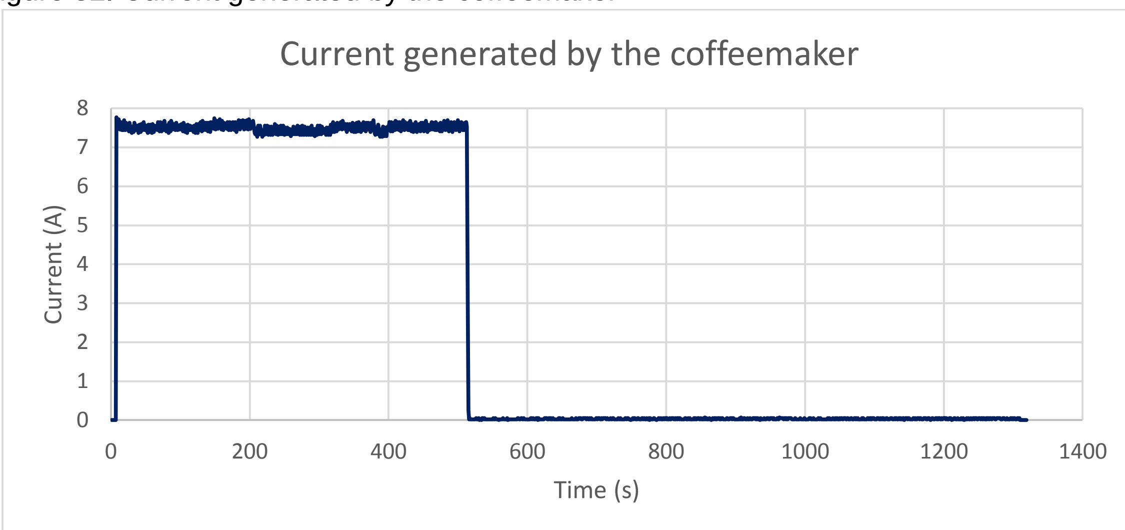


Source: The author

APPENDIX G
CONSUMPTION OF A COFFEEMAKER

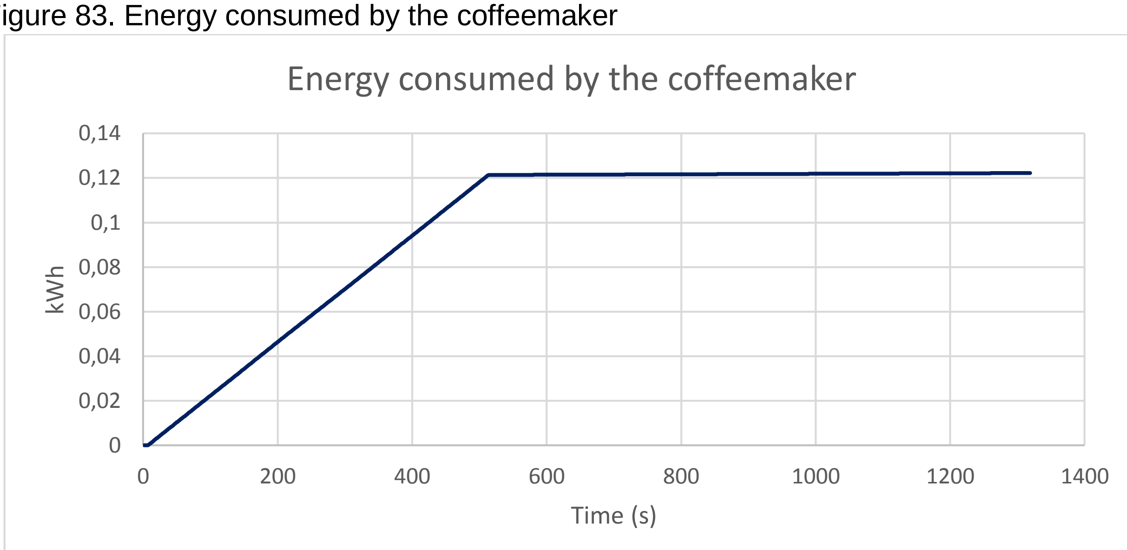
The coffeemaker Farberware, Superfast model, works at 120V and consumes 1000W. In the Figure 82, the behavior of the coffeemaker can be observed. It requires around 7,5A and 500 seconds to the coffee to be prepared. After that, it can be seen that there is a minimum current, approximately 50mA that keeps the coffee hot. The consumption can be seen in the Figure 83, where 0,121kW were consumed in 515s, making a projection of 0,8509kWh.

Figure 82. Current generated by the coffeemaker



Source: The author

Figure 83. Energy consumed by the coffeemaker

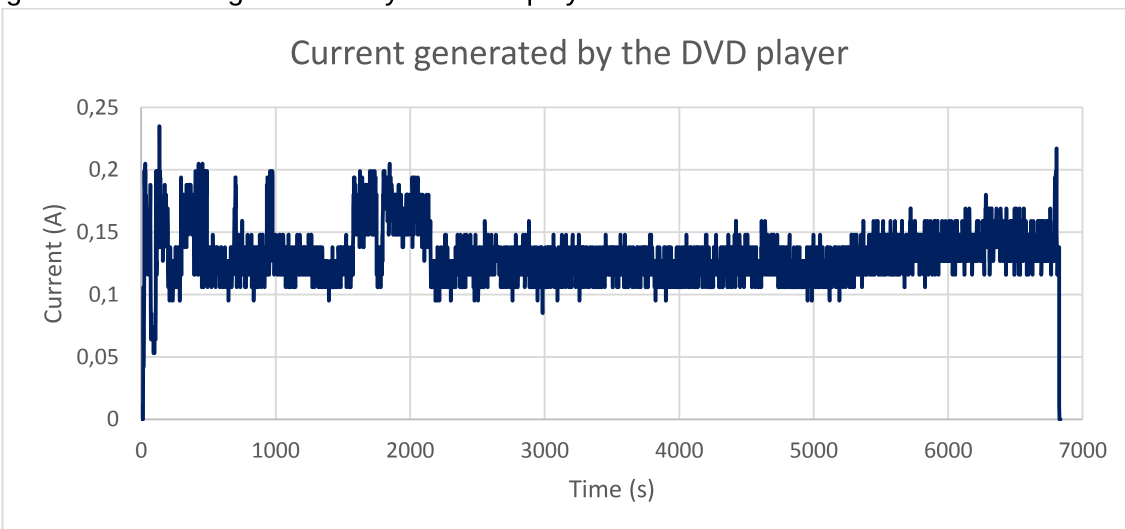


Source: The author

APPENDIX H
CONSUMPTION OF A DVD PLAYER

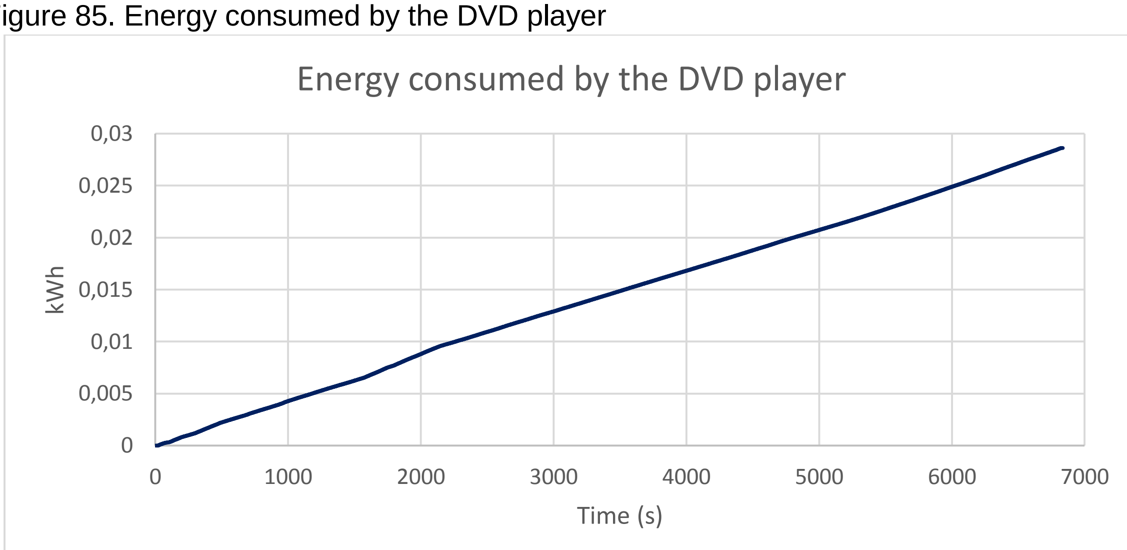
The DVD player Parker, model DVH385MD runs from 90 to 240V at 50 to 60Hz, and consumes 15W. The Figure 84 shows a low current, around 150mA during 7000 seconds approximately, until it is shut down. The Figure 85 shows the rising of the energy consumed, being 0,0152kWh.

Figure 84. Current generated by the DVD player



Source: The author

Figure 85. Energy consumed by the DVD player

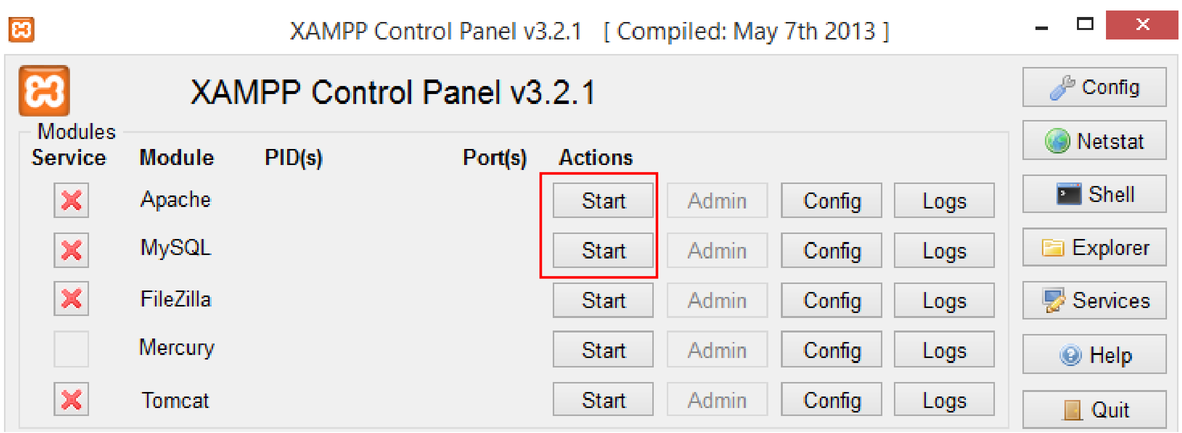


Source: The author

APPENDIX I
USER'S MANUAL

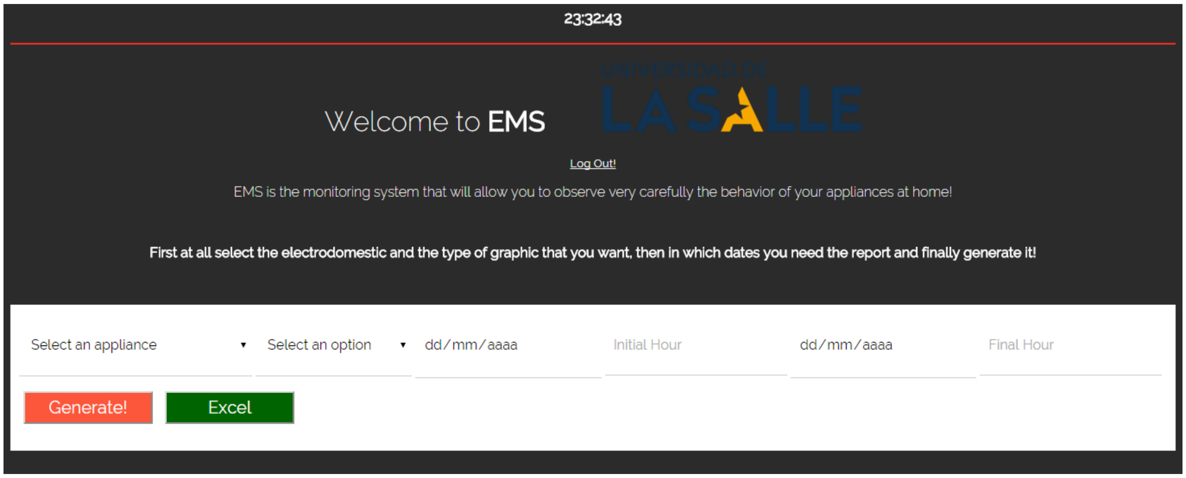
IT IS RECOMMENDED TO READ THE SAFETY INSTRUCTIONS BEFORE USING THE MONITORING SYSTEM SENSORS. IT CONTAINS ESSENTIAL SAFETY CONTENT FOR THE APPROPRIATED FUNCTIONING.

1. Contact your Internet provider to establish a unique IP for your computer. It prevents that the router changes the IP each time it is rebooted.
2. Inform to the manufacturer of the sensors the IP number assigned to the computer, so he can program the sensors with the correct IP. Also, inform the names of the appliances you want to measure, so the Admin can type them into the drop-down list.
3. Open XAMPP Control Panel, executed as admin.
4. Click on both *Start* buttons from Apache and MySQL to initialize the local server.



5. Identify the maximum current or wattage consumed by the appliance you want to measure.
6. Connect the appliance to the sensor, according to the maximum current: 5A or 20. The red light of the Wi-Fi module indicates it is on, and the blue light flashing proves it is communicating with the server.
   Note: The connection of an appliance that consumes more than 5A to a 5A sensor, will damage it.
7. Open the browser (Google Chrome recommended) and type in the Address bar *localhost/Arduino/index.php*, to open the webpage.
8. If you have already have an account, click on HERE to redirect to the LogIn window, and type your username and password. Otherwise, fill the fields to create and account and click on SIGN UP.
   Note: If you forget your username or your password, please email the administrator.

9. The main window of the monitoring system now is opened, after a successful login or signed up. The user can select in the drop-down list the appliance and click on *kWh* to visualize the graph of energy consumed, while clicking on the *$$$* to visualize the cost of the consumption in Colombian Pesos. It is necessary that the user selects the initial date, initial hour, final hour and final date.



10. If you decide to exit the monitoring system, click on *Log out*.
    Note: If you do not intend to measure any behavior of an appliance, please keep the sensors unplugged.
11. Stop the server by clicking on the *Stop* buttons from the Step 4.