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Reducing Energy Consumption Through the Use of Home Energy Management Systems (HEM) and Gamification

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ABSTRACT: *The increase in energy demand is leaving the conventional energy systems at a disadvantage, so it is necessary to investigate and implement strategies aimed at saving energy. Recent research shows that it is possible to achieve a reduction in energy consumption by installing energy management systems in the home. However, it is essential to evaluate such solutions from the point of view of users and their behavior towards these technologies. In this sense, we plan to develop a system that complements what has been done up to now, including strategies that try to educate users in the reasonable consumption of electric energy by adding gamification.*

Keywords: *Gamification, Home energy management system, Smart Home.*

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I. INTRODUCTION

The energy consumption of the residential sector is a key point in the current energy context, due to the remarkable contribution made by this sector to total energy consumption. This importance lies in the fact that, at a global level, entities such as the International Energy Agency (IEA), foresee a considerable increase in energy consumption for the coming years [1]. Facts such as the increase in the number of homes and equipment set within these, consumption habits and the search for comfort, are those that encourage the growth of energy demand in households.

In Colombia, the panorama is not different, projections made by the UPME (The Mining and Energy Planning Unit) and the Ministry of Mines and Energy in [2], show that the demand for electrical energy will increase exponentially from 2016 to 2030. In addition, in this same bulletin it is possible to see how in the country the residential sector is the one that owns the highest percentage of electrical energy consumption with 42% in 2015. An example of this is the increase of 21.23% from 2012 to 2015 in the department of Sucre, whose capital is Sincelejo, the city of our study.

At the global level, a variety of policies have been proposed that look to reduce the effects of energy generation and thus reduce environmental impact. These policies cover the generation of clean energy and the reduction of energy consumption in all sectors.

In this sense and taking into account that the residential sector has a significant contribution to total consumption, it is urgent that households make a more reasonable consumption, so finding a solution to this problem becomes urgent.

Therefore, the main objective of this work is to propose a tool that will intervene in the consumption of electricity in the household to achieve a reduction of this. Home Energy Management Systems (HEM) are a strategy that is achieving good results. For this, it is essential to characterize the residential energy consumption in order to identify the measures that must be implemented to generate greater energy savings in households.

In order to carry out the analysis of the information, this will be previously collected through surveys conducted in a certain number of households in the city of Sincelejo. According to the analysis of the information collected in the surveys, a HEM prototype is developed. For which initially the environmental variables of interest and devices of typical use in the home will be identified, then the wireless sensor network and the management system will be designed and implemented, to finally evaluate the performance of the prototype.

Gamification is the implementation of games in non-play spaces. Recently much research on gamification has been emerging, gamification has been applied in various contexts showing utility for the solution of various problems. Within all the environments in which it has been applied, there are also contexts that involve the care of the environment and the rational consumption of natural resources, that may be of great interest for the application of gamification, to achieve the rational use of electricity in the home. After evaluating the HEM, a gamification module will be added to determine if the use of the gamification can improve the efficiency of the HEM.

The present work is divided into 5 parts: in the first, the basic concepts. In the second, related works. In the third, analysis of the population for the pilot. In the third, the architecture design proposal. Finally, the last section shows the conclusions and presentation of the pilot.

II. BASIC CONCEPTS

TAn energy management system is a set of automated controls that allow you to monitor and optimize energy usage [3]. These systems that optimize energy consumption are applicable for use in smart homes, such as houses and buildings where home appliances and sensor devices are interconnected [4]. The sensors used for the monitoring of the devices are connected to each other forming wireless sensor networks (WSN). Sensor networks consist of a series of electronic devices that have access to the outside world, are small in size and can be located anywhere [5], [6]. They transmit the monitoring data in real time, which are used to evaluate the current state of the energy system and can be controlled remotely by an energy management system [4]. For their communication, the WSN use low-power wireless networks such as Zigbee [6].

2.1 General architecture of a HEM

The architectures proposed in the literature can be classified into different groups according to their similarities and although there are some more complex architectures, basically a HEM must have:

- A home area network (HAN): It is a residential local area network that interconnects devices within a house, such as: Sensors, intelligent plugs, intelligent thermostats and home appliances allowing communication between them, either through a wireless network or a wired network.
- Monitoring and control devices: They are final devices that are responsible for monitoring and controlling the energy consumption of household appliances.
- A processor: Used for concentration, storage and management of information.The server and the database would be located in this central module
- A gateway: It allows to connect he HEM with the outside, so that the remote access through Internet is possible.

This basic architecture has been raised from the review of the works of [7] to [28].

III. RELATED WORKS

This section presents some work related to energy management systems (HEM). Most of these systems allow users to save energy by monitoring and controlling household appliances.These HEMs can vary slightly in the way they work, but their architectures start from the basic architecture exposed. For example, while [9] uses Zigbee and PLC as communication structures, Zigbeeto transfer energy and power data of household appliances and lights, and PLC for the control of solar panels; [11] uses only PLC. Although in both cases it is possible to optimize the use of the energy in the home and to reduce the costs, [9] includes reduction of the consumption of energy and generation of renewable energy and [11] includes a module for the elimination of the energy in waiting. In the case of [29],they use a wireless sensor network based on Zigbee technology to develop a real-time monitoring system for household devices that has low power consumption, is reliable and low cost. Experimental testing of the system demonstrates that it is suitable for the management of home appliances in a flexible manner. In addition, this system allows to extend to a building or a community.

In other cases such as [30] and [31], HEMs with more elaborate architectures are presented. [30] proposes an iHEM for the management of domestic energy. The system relies on communication between intelligent devices through a wireless home area sensor network (WSHAN), a central power management unit (EMU), smart meters and a storage unit. For the communication, the iHEM uses zigbee in tree topology. The application is based on the apparatus coordination system; The consumer can turn on any equipment at any time without worry, regardless of peak time, and the iHEM will be able to suggest a convenient start time for the consumer according to the iHEM algorithm and notify the consumer. Consumer demands are processed in real time. This system reduces the consumption of electric energy generating local energy, prioritizing the use of home appliances and fixing prices in real time. The developed iHEM is flexible in allowing communication between the controller and the consumer using the WSHAN. In addition, with this application it is possible to efficiently balance the supply-demand and reduce costs of electricity and carbon emissions. In [31] a scheme for energy-sensitive intelligent households "Coordination of household appliances with power" (ACORD-FI) is proposed. In this scheme the consumer can connect an appliance at any time, regardless of the concern for peak hours. When the consumer switches on a device, the device communicates with the EMU to check for a suitable start time, ie the suggested time. ACORD-FI uses the wireless network of home area sensors to allow communication between the devices and the EMU. The EMU learns the amount of local power available from the power generation unit and the smart meter price information and provides a suggested start time. It is demonstrated that ACORD-FI reduces the cost of energy consumption of household appliances, significantly reducing the quota of appliances in the total energy bill and provides a saving in the energy bill.

Based on the fact that public service prices vary depending on the time of day, and that electricity consumption during peak hours costs more than electricity consumption during off-peak hours, [32] develops a home energy management system that allows to reduce the use of equipment in the peak hours and to reduce the consumption of energy, also diminishing the emissions of greenhouse gases. The system integrates wireless sensor networks for energy management applications in smart grids. The reduction of the contribution of the energy consumption achieved is 30%, this saving is achieved in a time less than a year that can increase when a greater number of apparatuses to the application is involved.

Unlike the previous cases, [33] complements the Zigbee communication with remote controls by infrared. The system uses a zigbee concentrator with IR code learning function, which allows the user to control the power and light outlets, the controller communicates with a server for the home and reports the power consumption information that can be Displayed by the user. This architecture offers more power reduction and user control capability than a general HEMS.

In some cases these systems have been tested using test benches that include typical home use devices, as is the case of [34] whichproposes an adaptation of intelligent home energy management system (AiHEMS) and using a Test bench with light and air conditioning. This system proposes a scheme of information convergence, service prediction based on dynamic pattern, and adaptive lightweight middleware architecture. The results of the tests show that savings of 18% and 25% can be achieved, while [35] saves up to 40% with an intelligent home control network using wireless sensor networks (WSN) for Data detection and power line communication (PLC) to send this data to a management station and control of household appliances.

Finally, we will mention the case of [36] that proposes a system that aims to reduce peak power demand and try to maintain the linear load curve without affecting the comfort level of the customers. For this, an algorithm is developed in Matlab that allows to effectively reduce the total energy consumption of households in peak hours when trying to change the operation of non-essential equipment and monitor the consumption of equipment individually. This algorithm manages to effectively control and manage the operation of household appliances to maintain the total energy consumption of households at peak times below a specified demand limit.

These studies show that it is possible to say that HEM represent a technological innovation designed in the context of the home to provide security and comfort and that HEM technology shows certain benefits that classify it as a viable alternative energy saving by the end user.

IV. ANALYSIS OF THEPOPULATION FOR THEPILOT

An essential point before proposing a system is to carry out an analysis of the population in which the HEM is intended to be deployed. This is why energy consumption has been characterized in the residential sector of the city of Sincelejo Colombia and, from it,identifyhow HEM should be implemented to generate greater energy saving within homes. This is because the amount of energy a home consumes varies considerably depending on its size, location, number of occupants and types of home appliances used.

In this study, we used data from the survey "Identification of typical home appliances, energy consumption and environmental variables involved in energy consumption in the residential sector of the city of Sincelejo", done by ourselves. This data collection instrument allowed us to know in the first instance which the most used household appliances are, so that we can select the ones that will be included in the HEM test bench. And secondly to know how muchthe average consumption of households is by stratum depending on the number of occupants in the house. This is because there is no data set with this information or any updated study.

In order to understand how the instrument will be applied, it is necessary to talk about the Socioeconomic stratification system in Colombia. According to the National Administrative Department of Statistics (DANE, for its acronym in Spanish) socioeconomic stratification is the classification of residential properties of a municipality, which is done in accordance with the Regime of Public Services in Colombia (Act 142 of 1994) [37]. All homes must have their respective stratum. The municipalities and districts, according to the norms, can have between one and six strata. Depending on the social and economic heterogeneity of their home, they are called [38]:

Stratum one (1) low-low
Stratum two (2) low
Stratum three (3) medium-low
Stratum four (4) medium
Stratum five (5) medium high
Stratum six (6) high

For the selection of the sample, i.e. the number of households per stratum to which the survey will be applied, data on the number of households per stratum and neighborhoods belonging to each stratum provided by government entities such as DANE and Stratification office of the Mayor's Office of the municipality of Sincelejowill be taken into account. The selected sample can be observed in table 1.

Table 1. Number of surveys per stratum according to the number of households per stratum.

STRATUM	1	2	3	4	5	6
NUMBER OF HOUSEHOLDS	23.713	14.146	5.886	2.483	893	272
NUMBER OF SURVEYS	201	200	196	188	165	116

To conduct the analysis of consumption, a total of 1066 surveys were conducted applying the technique of direct interview to families in the 6 strata. For the application of the instrument, the number of households per stratum was obtained, which was supplied by the stratification office of the municipality of Sincelejo. With this information, the amount of surveys to be carried out in each of them was determined using inferential statistics, using equation (1) that allows the calculation of the sample size when the population size is known.

$$n = \frac{\mathrm{N}\ x Z^2 xpxq}{d^2 x(N-1) + Z^2 xpxq} \quad (1)$$

Where,
N = population size
Z = confidence level
P = probability of success
Q = probability of failure
D = precision

3.1 Characterization of households:

The amount of energy consumed by a household varies considerably according to its size. The size of the home, expressed as the number of inhabitants in the dwelling, is a variable that hasrepercussions on energy consumption at a significant level. Fig 1 shows the average number of occupants per dwelling in each stratum, which is approximately 4 occupants for strata 1 to 6. So it is possible to say that a typical family in the city of Sincelejo is made up of 4.2 members.

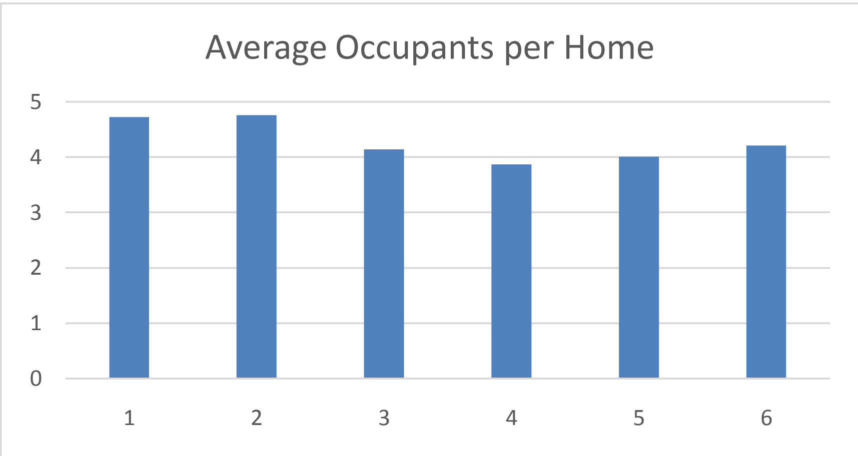

Fig 1. Average number of occupants per dwelling per stratum

3.2 Analysis of consumption:

The average daily consumption per stratum was also obtained from the survey application. Fig 2 clearly shows how the energy consumption increases as the stratum increases, meaning that the lower strata have lower energy consumption than the high strata.

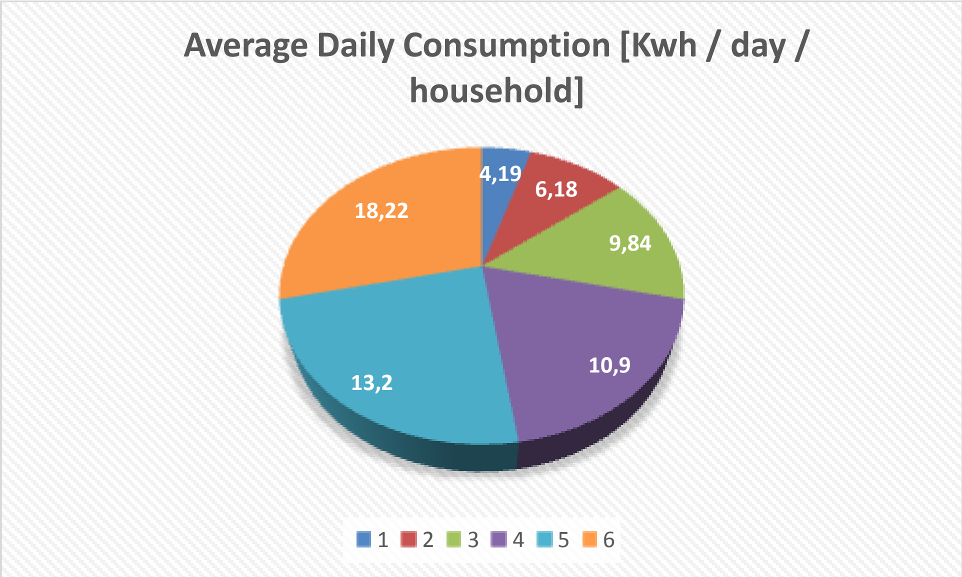

Fig 2. Daily consumption average per stratum

Fig 3 shows the probability distribution of daily consumption per stratum. For both cases, the x-axis represents consumption versus the number or proportion of households with a given consumption on the Y-axis. As it can be seen, these graphs of measurement values tend to cluster around a central point (the mean); generating a normal distribution curve. Thus, the behavior of the consumption of electric energy per stratum of the total population will tend to be the same of the representative sample of the population that has been studied.

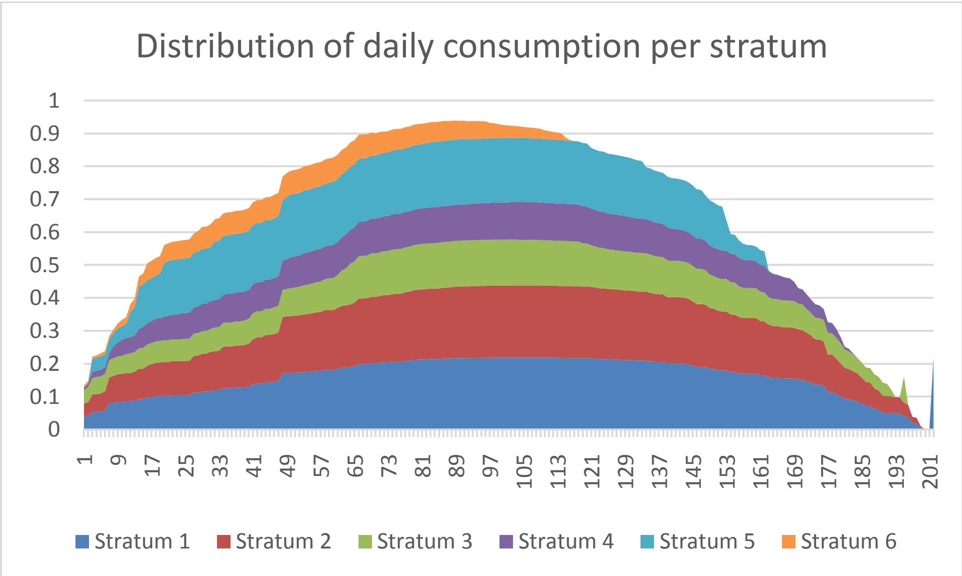

Fig 3. Daily consumption probability distribution by stratum

3.3 Characterization of household appliances of typical use in the home

In a house, the great majority of the apparatuses and equipment work with electrical energy. We know that the use of one or the other house appliance varies from household to household, however there are some appliances that, for the benefit they provide,are of typical use in homes. Fig 4 shows which appliances have the highest penetration according to the socioeconomic stratum. This graphic then shows how, as the stratum increases, the amount of household appliances used increases, it can also be observed that the most used house appliances are those that seek to satisfy basic needs in homes such as: Luminaires, refrigerator, TV, blender, iron, washing machine and air conditioning or fan, depending on the stratum. The lower strata use a fan and the higher strata use air conditioning, due to the hot weather of the city of Sincelejo.

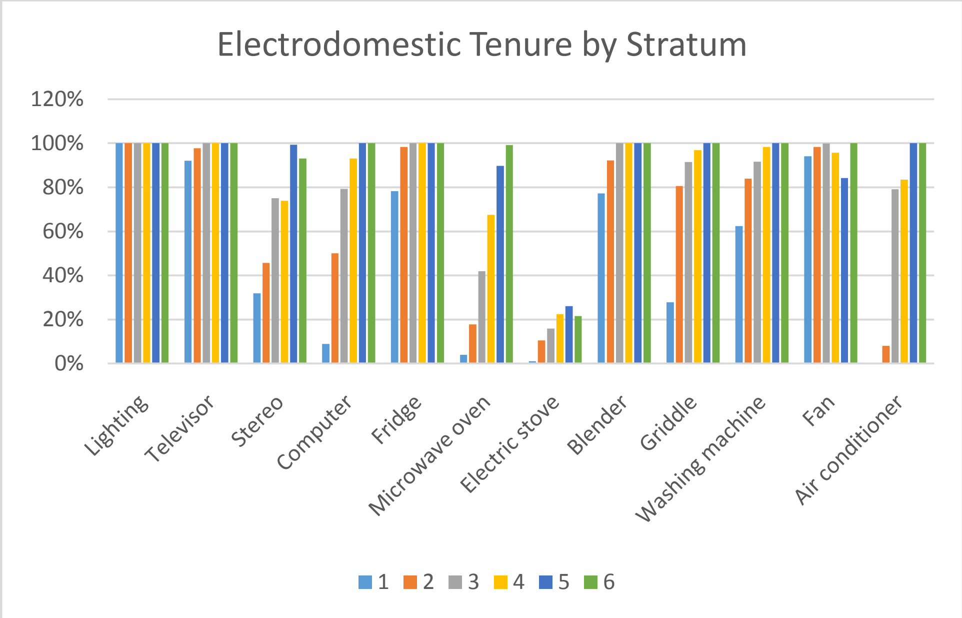

Fig 4. Holding of appliances by stratum

3.4 Reduction of Consumption

The inefficient management of electric energy in households is the one that generates a negative impact on daily energy consumption and therefore the monthly consumption, which is reflected in electric energy bills.

The correct use of house appliances according to the needs of the home helps to reduce consumption to a large extent.Waste of energy is due in large part to unconcerned attitudes in the occupants of the dwellings such as leaving lit appliances that are not using or abusing the lighting. However, measures such as regulation of temperature and luminosity, turning off equipments that arenot being used would bring about a reduction in power consumption.

For these reasons, it is considered feasible to introduce energy management systems into households that help users to control energy consumption and to know consumption in real time, so that they can take measures to reduce energy consumption without affecting comfort.

V. ARCHITECTURAL DESING PROPOSAL

To achieve the goal of reducing electric energy consumption in the homes of the city of Sincelejo, the development of a home energy management system (HEM) is proposed that involves the capture of data in the household of bothvariables Environmental and energy consumption.

The system consists of a sensor board that is connected to an Arduino development platform, this board consists of a sensor of environmental measurements or energy consumption and a Zigbee module that will allow the transmission of the data to a central module where they will be stored and may be consulted. The one that is based on Arduino, allows to program from the same development environment (IDE) of Arduino, simplifying the programming and obtaining a greater accessibility to the users of the home. This project is based on the Internet, free hardware and software for data capture and control over devices. Fig 5 shows the diagram of the system.

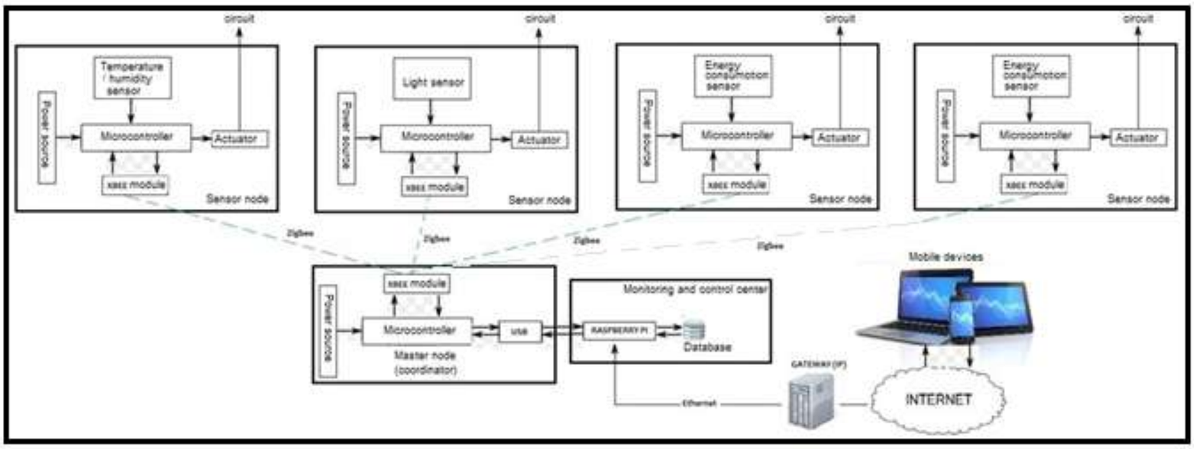

Fig 5. System Diagram

A prototype of the system will be implemented in order to carry out an analysis of the endowment of typical household appliances, the hours of use and the power consumed by the household appliance, which will allow us to finally define hourly usage patterns hourly ofelectric by house appliance by user or by household by stratum, to then establish consumption profiles.

After this analysis, it is proposed to include a gamification approach in the system that allows to improve the efficiency of the system of energy management in the home, so that a greater energy saving can be achieved. The idea is to use an online game that connects to the home, which tracks the use of each player's energy through the HEM, taking into account the energy consumption of each connected device. This information collected by the HEM is sent to the game and taken into account for its development and the allocation of rewards.

VI. CONCLUSIONS AND PRESENTATION OF THE PILOT

The efficient use of energy in the home should not go hand in hand with the sacrifice of comfort. On the other hand, if the occupants of a home can be comfortable while saving energy, this will encourage them to seek permanent savings and not just for a short period of time. A HEM system that incorporates a gamification approach will allow a change in the habits of the members of a household that leads them to obtain a greater efficiency in the use of the electricity.

To achieve the goal of our research, we are developing the prototype of a home-based energy management system based on wireless sensor networks that work under the IEEE 802.15.4 standard, use the Zigbee specification. Also, the prototype includes mobile devices, as user interfaces, which allow to manage and monitor the consumption of energy in the home.

The system consists of a network of wireless sensor nodes specially designed to capture the variables of interest and a monitoring and control center. The wireless sensor network enables the transfer of data from the variables to be measured and has a defined number of nodes; in turn, each node can measure the power consumption of the appliance or the electrical appliances to which it is connected. The nodes will be based on a board that uses hardware and free software equipped with Zigbee communication modules and sensors that can be of energy consumption, light intensity or temperature and humidity. Each sensor node measures the environmental variables and the captured information will be transformed into digital information and transmitted to the main node (coordinator of the zigbee network) through the zigbee specification. This means that each node will process the information and add a header to the data so that the coordinator receives them and can identify from which node they come. The main node will be directly connected to the platform raspberry pi that fulfills the functions of monitoring and control center (database, web server), which will be in charge of performing the analysis of the data. In addition, it will provide a user-friendly interface where you can observe historical and real-time graphs of each of the sensors. Figure 6 shows the hardware details of the current system.

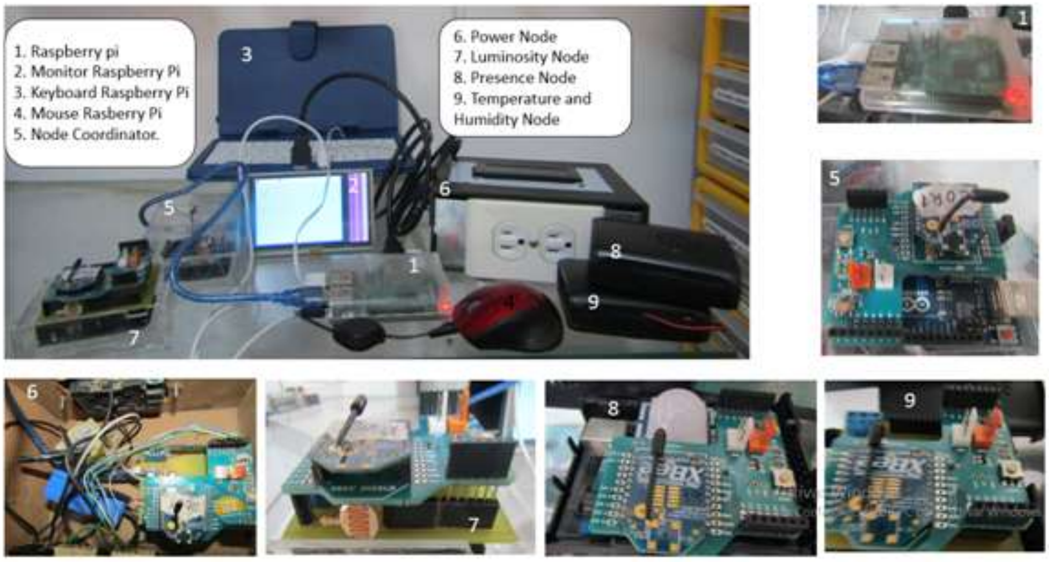

Fig 6. System Prototype

The system will also allow remote access to the monitoring and control center, so that the user can remotely access the information collected and control all monitored variables. For this, a web tool must be built that allows the capture, monitoring and analysis of the data.

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