# Development of a prototype to improve energy efficiency in the residential sector

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July 2016

**Abstract**

In order to respond to the growing energy consumption in the world and the corresponding CO2 emissions, society needs to focus on measures that enable a reduction and greater efficiency in the use of energy. The residential sector, representing 25% of the total energy production, is one of the sectors in which these efficiency measures can be applied. However, the application of measures aiming for adjustments of the energetic situation in this sector should regard the role of the user, whose behaviour can be affected by the way he faces the information about energy consumption (feedback). This feedback, enhanced by an in-home device designed in such a way that enables the translation of that information into an appropriate energy saving action, is taken as preponderant to an energetic rationing. Thus, this work is focused on the development of a prototype, using the microcontroller Arduino, the Energy Box, characterised by a user friendly interface based on the current commercialized IHDs (In-Home Displays). This prototype is aided by an alert mechanism that operates with incorporated sensor readings, being supported by a web component that among other functionalities provides more detailed information about domestic consumption and allows the sharing of energy information among users. The prototype, tested for seven days in the house of a user, results in an energy reduction of 4%, strengthening the importance of the existence of a mean of monitoring given to the user regarding his energy consumption profile.

**Keywords:** energy efficiency, feedback, user behaviour transformation, In-Home Display.

## 1 INTRODUCTION

Over the last few years, energy demand has been considerably increasing, mainly in developing countries, where economic and population growth is more accentuated. It is expected that in 2030 this demand will increase by 50% [1]. In particular, the residential sector accounts for 25% of total energy consumption where, in OECD countries, 55% are related to space heating, 4% to consumption in the kitchen, 4% to lightning and 15% to the use of household appliances [2].

It is then crucial the improvement of energy efficiency, as one of the strategies to apply in order to respond not only to energy security challenges and economic development but also as a way of ameliorating concerns regarding climate changes, due to CO2 emissions generated from energy production. The concentrations of this gas have been increasing significantly since the last century when compared with the ones of the pre-industrial era: in 2014, these concentrations were 40% higher than in the second half of the 19th century, with an increase of 2ppm/year in the last ten years. In 2013, electricity production for the residential sector accounted for 11% of global CO2 consumption [3].

In recent years, an effort to reduce energy demand and therefore to consider a sustainable future has been taken into account, as the example of the EU agreement in which was settled the improvement of energy efficiency by 27% and CO2 reduction by 40% until 2030 [4].

Therefore, the intervention in the residential sector can also be considered as a key point regarding a sustainable future. In this sector, the energy user can have a direct influence in the way energy is used, however, due to several factors like bad habits or lack of knowledge, the energy potential efficiency is not optimized. In most of the cases, the energy user is not able to calibrate a system which allows an ideal comfort, in the most efficient way and, thus, leading to unnecessary costs, especially in lighting and cooling/heating. Since that technological development in this sector is not enough to ensure the reduction of energy consumption in order to provide a way to change supply and consumption patterns, it is necessary to consider the interfaces between the user and the devices and the way they can be improved [5]. The challenge lays in providing an effective way of making energy use noticeable to the user and drawing attention to the consequences of each action performed. Therefore, energy systems designs should not only be focused on consumption information but also on how information can be translated into appropriate energy-saving actions [6] [7]. The lack of exploration of this potentiality in current systems leads to poor energy saving results and to a discouragement on the benefits of these systems making the users to discard the systems altogether [6, 8].

## 2 FEEDBACK

Most of the time, consumption related to the usage of domestic energy is overlooked by the user. The most part of the population has only a rough idea about the energy used for various purposes and discards how small changes in behaviour can represent a substantial increase of energy efficiency [5]. In this context, it is relevant that users can have a closer contact with their energy output, relying in a type of information that makes energy consumption more visible and easier to understand and control. Therefore, it is crucial to focus on the behaviour of the user and how it can be changed, allowing a better interpretation of the feedback given to the user and helping him to make the best decision in a continuous and progressive way. Darby [5] divided feedback into two branches: indirect feedback, in which information is processed before reaching the user (bills) and direct feedback, where the update of information is done more frequently, usually supported by a display installed in a dwelling.

In the last decades, several studies tackled the influence of the type of feedback provided to the user in the way energetic consumption is perceived and the effects on possible savings. Wilhite e Ling [9] concluded that the enhancement of bill presentation resulted in savings of about 11% and according to Abrahamse et al. [10], savings were of 5,1% when providing an electronic feedback of total energy consumption. In terms of direct feedback, results are even more promising: the use of a domestic device which is able to display energetic consumption implies savings around 5-21% [11, 6, 5]. This work is intended to settle in a closer approach to the user making use of a more direct feedback, in which outcome information, frequently updated, has as aim the modification and control of daily routines, being this a necessary element to a learning process on how to control effectively energy usage in a long period of time. To successfully enhance direct feedback several aspects should be considered:

- Capture the attention of the user linking the necessary confidence he needs to get with the technology and with himself;
- Solid connection between performed actions and inherent effect;
- Exploration in such a way that triggers user awareness for energy savings, such as money savings or reduction of pollutants emission;
- Frequency: "the shorter the period of feedback, the more effective it will be" [12];
- Specificity: information should be displayed in a clear and direct way and should be compatible with the methods of energy analysis of each user;
- Insertion in a comparative context, in which the user is able to monitor his progress [13];
- Improvement of visual and graphical design [6].

## 3 USER BEHAVIOUR TRANSFORMATION (UBT)

The stimulation of the change in behaviour of the user is influenced by several factors such as gender, age, culture and even the number of inhabitants or occupants, which are variables that are difficult to be modeled, making it difficult to find an optimal judgment of what standard actions should be performed in order to promote energy savings. Apart from these factors, it is important to draw attention to the habits of the user, shaped by social rules, user beliefs and house rules [14, 15] and, like society, they can (and must) evolve. However, an important aspect relies on the fact that not all user habits can be changed, once that tolerance to change is limited. In addition, they can be influenced by personal preferences as well as involving community and geographic location. When all of these aspects are not considered, there may be a discomfort of the user regarding the system, leading him to discard it [16]. Several studies regarding the influence of these variables in energy saving behaviours have been performed and although they help to understand that some variables should be considered important, the discussion of whether a variable is, or not, important, still remains. Nonetheless, even though they all should be considered when designing a feedback system to promote UBT, the main factors identified lay on education and motivation of the user.

### 3.1 UBT System Design

In order to promote the modification of user habits, information related to energy consumption has necessarily to be easily accessed and understood, in an attempt of progressively increase consciousness of the impact of his actions and choices [9]. The provision of information not very well explicit and concise of possible actions to adopt makes the user get confused, discouraging him and resulting in an ineffective reduction of energy consumption.

According to Fischer [6], the user need not only to be alerted for his consumption, but also to be provided with the means to evaluate the performance over time. This study was later deepened by Froehlich [17], who establishes ten dimensions applicable to UBT in a concise and well defined way: frequency, measuring units, information granularity, push/pull, presentation medium, location, visual design, recommending actions, comparisons and social sharing. These dimensions can be used to evaluate the quality and efficiency of graphical interfaces in the energy domain and cover educational up to motivational aspects considering the transformations of the user's behaviour.

Several researches point out that the development of adequate characteristics of a feedback mechanism that triggers UBT requires the involvement of the final user since the design process [18], following methodologies like participative co-design, in order to ensure an effective and interactive evaluation of usability and other important characteristics that must be taken into account to effectively trigger UBT.

### 3.2 Energetic platforms

There are currently in the market various types of energy reporting platforms that can be used as a basis to trigger UBT. Notifications given to the user about aspects that require his attention, like energy inefficiency, is performed through different means:

- **In-Home Displays (IHDs)**. Systems installed in strategical points of the dwelling and designed to notify in an immediate way. Their great interactivity allows the user to navigate among different types of information, providing a high feedback level.
- **Energy management website/software**. The systems act as a way of complementing information from other platforms. However, despite providing a high variety of information, they need the initiative of the user to be used.
- **In-Home Notifiers (IHNs)**. Like IHDs, these systems are strategically installed in the dwelling and are cheaper than IHDs. Notifications to the user are given by lighting changes, sound emissions or even through physical interaction.
- **Enhanced Utility Reports**. Reports (paper or digital) sent by the energy company, give the user information about consumption in a more simplified way and provide as well comparative reports with the previous results, and information is displayed in terms of other measuring units, being energy and expenditures the most common.

## 4 PROTOTYPE DESIGN

The designed prototype, the Energy Box, is based in IHD platforms characteristics and aided by lighting and sound, typical elements of IHN platforms that allow the user to assess in a more direct way some possible problem related to his consumption and the high level of quality and detail of information, characteristics of the energy management website/software and enhanced utility reports, are explored as well.

The functional architecture of the Energy Box is shown in Figure 4.1. The results of sensor readings allow the system to identify possible problem, from which are suggested possible actions in order to optimize user consumptions. After the suggestion, the system provides the forecast of outcomes of the possible action. The information system will influence the user to make a decision, expecting that he acts according to the suggested action; after he performs the action, it is expected that it influences the new sensor readings. The communication of outcomes is done as a way to aware community around, hoping that it triggers a motivation to a greater effort for an efficient behaviour, after the comparison of his results with other people.

Thus, the Energy Box will work as a background processor, functional 24 hours per day, managing hourly, or minute by minute, the energy usage of a dwelling.

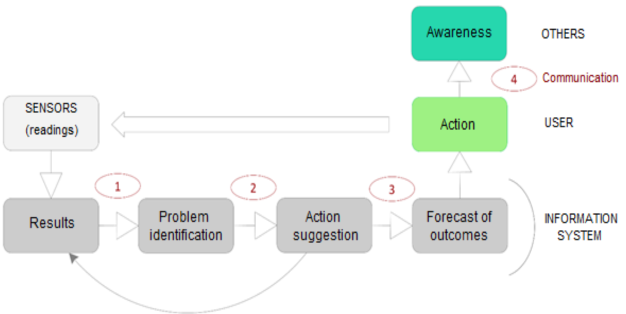


Figure 4.1 Architectural concept of the system to be developed.

## 5 ENERGY BOX: HARDWARE ARCHITECTURE

### 5.1 Hardware features

The main features of the Energy Box prototype are:

- Electric current reading;
- Temperature and humidity reading;
- LPG detection;
- Date and time log;
- User interaction through display with directional joystick;
- Warning/Information system;
- Information storage in memory card;
- Communication with internet.

### 5.2 General Operation

The Energy Box is divided into two main structures: EBNucleus, designed to allow interaction with the user and to establish communication with the internet; EBElectron, responsible for current readings of the dwelling. Figure 5.1 shows the schematics of the Energy Box operation mode.
EBElectron is the structure responsible for the readings of current consumed in the dwelling using a current sensor connected to the single-phase electric wire of the electric panel. EBNucleus consists of the EBProton and EBNeutron structures: EBProton is considered the “heart” of the prototype, since it is the one where user interaction is accomplished. The incorporated display allows the visualization of consumption profiles of all of the installed sensors. Luminous and sound signalling is activated according to the type of alert which enables the user to have a quick perception in detecting possible anomalies in his consumptions; EBNeutron is the structure responsible for sending and receiving data from the internet.

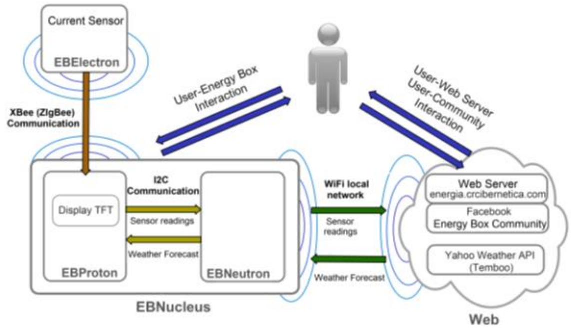


Figure 5.1 Energy Box operating mode diagram.

#### 5.2.1 EBElectron-EBProton interaction

Current readings are sent, via Zigbee protocol, from EBElectron to EBProton. The communication between these two structures is established with the help of two antennas that communicate wirelessly. Data transfer is performed using serial communication in the direction EBElectron → EBNucleus: Serial → Serial1.

#### 5.2.2 EBProton-EBNeutron interaction

All sensor readings and other information received from EBElectron are forwarded, via the I2C protocol, from EBProton to EBNeutron, in the direction Slave-Master, that, in turn, sends data to a preconfigured web server and to the social network Facebook. In the opposite direction, EBNeutron sends, through

### 5.3 Hardware Description

#### 5.3.1 EBProton

EBProton is the central component of the developed system, since it is constituted by the main interface in which the user can interact. It comprises the microcontroller Arduino Mega 2560 with a 1,8’’ attached TFT Shield. The sensors of temperature, humidity and gas are connected to the microcontroller, as well as the alert/information indicator LEDs, the sound emitting device piezo, an RTC clock and the XBee antenna that receives electric current data. The final assembly in shown in Figure *5.2*.

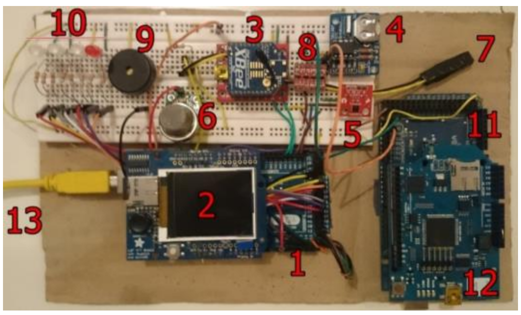


Figure 5.2 EBProton final assembly.

- **Sensors’ calibration**

Sensor1 reads inside temperature and relative humidity of the dwelling. The calibration for temperature was done using a thermopar with a precision of 1% and the fit of the readings are shown in Figure 5.3.

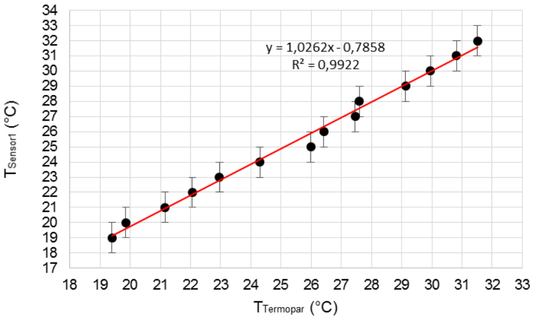


Figure 5.3 Liner fit used in calibration of Sensor1, for temperature readings.

As all Sensor1 temperature readings, $T_{Sensor1}$, are covered by the error of the thermopar they are admitted as the ones to take into account to the developed prototype.
In order to calibrate humidity readings of Sensor1, $HR_{Sensor1,exp}$, an EnergyOT Ambient humidity sensor was used. From the fit of the registered readings, the equation used to obtain relative humidity inside the dwelling, $HR_{Sensor1}$, is:

$$HR_{Sensor1} = 1{,}0074 \times HR_{Sensor1,exp} - 1{,}3657 \qquad (5.1)$$

Sensor2 is a chemical sensor that with a high sensivity to LPG. Although its dependence with temperature and humidity it is considered the following equation to obtain LPG concentration with the variation of the voltage detected in the sensor $V_{RL}$:

$$GLP(V_{RL}) = \left(\left(\frac{5}{V_{RL}} - 1\right) \times 0.08546\right)^{\frac{1}{-0{,}422}} \qquad (5.2)$$

### 5.3.2 EBNeutron

EBNucleus requires another Arduino microcontroller, assembled in EBNeutron, due to a conflict in the SD pin of both Shield Wifi and TFT Shield, impossible to manipulate via software,thus making it impossible the existence of these two shields in just one Arduino.

### 5.3.3 EBElectron

EBElectron final assembly is shown in Figure 5.4.

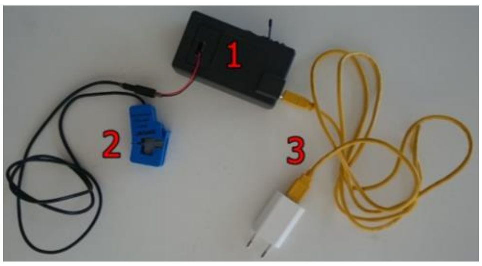


Figure 5.4 EBElectron prototype.

The current transformer (CT) is a sensor characterized by a primary winding, a magnetic core and a secondary winding. It is designed to produce an alternate current in its secondary winding, $I_S$, proportional to the one measured in its primary winding, $I_P$. Knowing that the sensor measures a maximum of 100A AC, correspondent to the RMS value of the maximum current the sensor can handle we have that the measurable max peak-current is

$$I_P = \sqrt{2} \times I_{rms} = 1.414 \times 100\ A = 141.4\ A \qquad (5.3)$$

and the current at the output, defined by number of turns ($Ratio_{TC} = 2000$ in this case) is

$$I_S = Ratio_{TC} \times I_P = 0.0707\ A \qquad (5.4)$$

Once Arduino can only handle voltages between 0V and 5V, current needs to be converted into acceptable voltage values. To do this, a burden resistor, $R_{burden}$ (R12), is added. Arduino cannot handle negative voltages, so there is the need to add 2,5 V to sensor voltage to make voltage measurable from 0V to 5V: this problem is solved by adding R10 and R11 (avoiding too many energy consumption) and C1 (low reactance) to provide an alternative path for the alternating current to bypass the resistor. After these modifications to the assembly of EBElectron, its software programming requires a calibration value $Y$, where theoretical value of $Y_t = \frac{Ratio_{CT}}{R_{burden}} = 60.606\ \Omega^{-1}$ was the one admitted.

Burden resistance tolerance is $\pm 5\%$ and for the CT this tolerance is stated in $\pm 3\%$ meaning an expected deviation of 8%. The calibration of the CT was done comparing its measures with a Xindar current sensor[1] and, in fact, it was registered a maximum of 8% deviation to the calibration sensor. However, despite the fact that datasheet of Xindar sensor does not have information about measuring error, it is expected an associated precision.

The value of the voltage supplied to the dwelling was also measured with the Xindar sensor, and the average of the registered values was 225 V, thus having as equation to calculate apparent power consumed in the dwelling, $P_{ap.}$:

$$P_{ap} = V_{hab} \times I_{rms} = 225 \times I_{rms} \qquad (5.5)$$

# 6 ENERGY BOX: SOFTWARE ARCHITECTURE

## 6.1 Software features

The main features of the Energy Box prototype are:

- Simple and fluid interface menu navigation;
- Sensor readings visualization;
- Energy consumption forecast;
- $CO_2$ and real-time expenditures visualization;
- Tariff comparison;
- 3 days weather forecast;
- Standby power estimation;
- Configuration of consumption settings;
- Alerts/information mechanism, through visual, lighting and sound elements;
- Email alerts;
- Consumption visualization in an web server;
- Social sharing of information (Facebook);
- Memory card data log.

[1] *Datasheet* available in: http://www.xindar.com/assets/xindar-multimetros-pin600_0312.pdf.

### 6.2 General operation

A direct feedback system is explored, where the interface with the user is achieved in EBProton as well as in a web server.

### 6.3 In-home interface

The in-home interface is done through the screen and the joystick in the TFT Shield. There are seven menus that provide information about energy consumption, sensor readings and atmospheric variables, one home menu and two designed for user and SD settings.

#### 6.3.1 Menu 0: SD Settings

In this menu, the user is able to reset all of his consumption values and settings and to safely eject the SD card.To avoid bad data when the Energy Box needs to be shut down, safe SD ejection option closes all ".txt" files and the message "Safe to eject SD Card!" shows up after 3 seconds.

#### 6.3.2 Menu 1: Weather

After the start of the Energy Box, weather information is obtained after the user presses the "OK" button of the joystick for 3 seconds; after this interaction it is updated every 8 hours. To retrieve weather information, EBProton requests EBNeutron to connect Temboo that, hereinafter, connects to Yahoo Weather server; after data reception, EBNeutron sends it to EBProton. Weather forecast for the current and next two days shows up in the screen illustrated by associated images and textual description of the conditions (Figure 6.1).

In this menu the user can as well watch current humidity and temperature conditions of the dwelling.

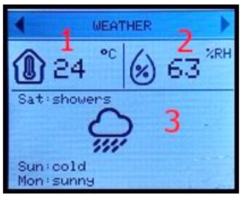


Figure 6.1 Weather menu.

#### 6.3.3 Menu 2: Home (Date and Time)

Home menu displays date and time and current tariff period, it informs the user about the best time to use energy and, specifically, the washing machine and provides the information of the inside temperature (Figure 6.2).

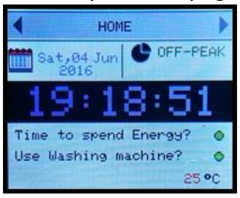


Figure 6.2 Home menu.

Date and time are programmed to change automatically according to the current time (winter/summer). Temperature information changes its colour according to the current value (blue for temperatures lower than 20 °C, red for values greater than 27 °C and green otherwise). After the definition of the tariff plan, the information of the current energy period is shown (Normal/Peak/Off-Peak). If none of the tariff plans is yet selected the user will be asked to go to "Settings Menu" in order to insert it. In case of being in a Peak Period, the user is informed about the time left for the next Off-Peak period, preventing him of wasting unnecessary money in a device whose use can be re-scheduled for the cheapest period.

The information about the "best time to spend energy?" and to "use washing machine?" depends on the current tariff period. The circular marker for the first question changes its colour between green (off-peak period), red (peak) or blue (normal tariff). The second question is related to the use of the washing machine (co-participative design feature, requested by the user) and its corresponding circular marker colour depends as well on weather conditions:

- If on off-peak period:
    - Green colour, if weather forecast indicates no precipitation, meaning that the washing machine can be used and clothes can dry outside instead of using drying machine;
    - Yellow colour, if rain is anticipated.
- If on peak period the marker will have red colour.
- If the tariff plan is normal: Red colour, if precipitation is anticipated, green otherwise

#### 6.3.4 Menu 3: Power

Apparent consumed power is shown through a ring meter and its numeric value (Figure 6.3). After the user defines its contracted power and calculates standby power, both values are shown in this menu.

The connection status with EBElectron is translated by the circle represented in Figure 6.3 (4): in case of having a constant red light a failure in communication exists.


Figure 6.3 Power menu.

#### 6.3.5 Menu 4: Energy

This menu shows the total and current bill energy consumption and provides the user the ability to compare its consumption with the national electricity consumption average in the residential sector of 1114.7 kWh per inhabitant per year (Figure 6.4). In case higher consumption than the average the message "above average by x %" is shown in red; otherwise, the message "below average by x %" will appear in green.

This comparison is made assuming a linear rate of consumption in a certain period: consuming 10 kWh in a day will significate on a forecast of 300 kWh in 30 days, for example. To estimate energy consumption, an average power value is used, $P_{av.}$, derived from the last two current readings sent by the EBElectronand the time interval $dt$ between the reception of these two values. Thereby, energy, $E\ (kWh)$, is given by:

$$E = \frac{P_{av.}}{1000\ W} \times \frac{dt}{3600\ s} \tag{6.5}$$

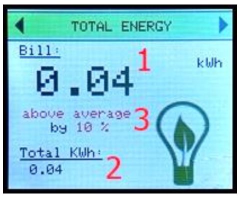


*Figure 6.4* Total Energy menu.

### 6.3.6 Menu 5: $CO_2$ Emissions

Menu 5 (Figure 6.5) provides information about estimated $kg$ of $CO_2$ consumption (total and for bill period), using the emission factor, $FCO_2 = 185.49\ g/kWh$.

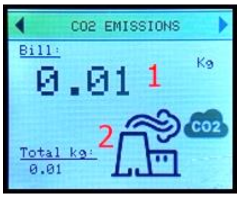


Figure 6.5 $CO_2$ Emissions menu.

### 6.3.7 Menu 6: Money Spent

"Money Spent" menu (Figure 6.6) shows current bill cost and expenditures since the first time of use of this device. The expenditures estimation takes into account some energy company taxes as well as a VAT of 23%.

The user is also provided with information about tariff plan and current price and with the money left to spend (pre-defined) until the end of the tariff period.


Figure 6.6 Money Spent menu.

### 6.3.8 Menu 7: Gas Detector

With the aid of a ring meter with a colour gradient from blue to red the concentration of LPG in ppm is shown as in Figure 6.7.


Figure 6.7 Gas Detector Menu Screen.

### 6.3.9 Menu 8: Tariff Comparison

Menu 8 shows the comparison among three types of tariff plans: normal and dual (weekly, daily). It allows the user to conclude the best plan to use regarding his money savings. If the used tariff is the best, the message "For now, your tariff is the best!" in green is shown; if it is not the best the message "For now, your tariff is not the best!" is shown in green; if the tariff plan is not yet defined the message "No tariff plan selected" is shown.

### 6.3.10 Settings

"Settings" Menu allows the user to configure the power settings, the tariff plan and respective prices, choose the desired amount of money to spend for the bill and the number of inhabitants.

- **Power Definitions**

The user is able to insert contracted power value of the dwelling, the desired power he pretends to spend and also calculate standby power. To calculate standby power, the Energy Box collects power data every 30 seconds for 30 minutes to take into account the ON/OFF states of the fridge. In order to proceed to the calculations, the user is asked to turn off non-essential devices in order to obtain a reliable standby power value. After 30 minutes of data collection, the average power is considered as the standby power for the dwelling.

- **Tariff plan definitions**

In this sub-menu the user configures the prices for the available tariffs used for the calculations of expenditures.

- **Expenditures definitions**

The user is able to define his billing period and choose how much he pretends to spend during that time.

- **Householders definitions**

For the purpose of comparing energy consumption of the dwelling with the national average per habitant it is asked the user to insert the number of inhabitants.

### 6.3.11 Events

In the case of certain conditions are established, the Energy Box displays a window with a message referring to that event. To ensure that the user is confronted with the respective message and therefore makes a conscious decision, the navigation for the menus can only be done after he presses the "OK" button of the joystick.

As an auxiliary mechanism, these windows are complemented by sound elements that stay active while the condition is established in order to provide the user with a quicker perception of some possible anomaly in the consumption. Each one of the four existing LEDs corresponds to a defined variable: LED1 corresponds to changes in temperature, LED2 to changes in power consumption, LED3 to current tariff period and LED4 to the quantity of LPG detected. Apart from these lightning elements, the installed piezo emits sound with a characteristic frequency and duration to help a faster identification of the quantity in question. In certain conditions it is also sent an email to the user account; it was used a Gmail account that, through "Internet of Things", establishes communication with Temboo platform, reducing the need of too much coding in the Arduino.

- **Consumption alerts**

Power, energy, expenditures, LPG and temperature are associated to the emission of alerts, when certain values are reached.

In order to respond to the comfort of the user, alerts are emitted with the variation of temperature; the main purpose of this feature is to influence to way of use of the air conditioner, that most of the time is turned on as a routine. If the temperature is below 20 °C, a blue light turns on, shown on the screen represented in Figure 6.8; for temperature above 27 °C a screen referring this condition shows up and a red light turns on; otherwise, LED1 remains with green light turned on; sound alerts are emitted for the first two cases, with a duration of 2 seconds and a frequency of 1000 Hz.


Figure 6.8 Low Power alert screen.

Although LED1 stays turned on with the respective colour correspondent to the condition established, sound and visual alerts (in the display) are triggered every 8 hours.

When the apparent power reaches 80% of the contracted power, or if it crosses the desired power value (defined in “Settings” Menu”), LED2 will turn on a red light and a sound with frequency 1500 Hz is emitted, with a duration of 10 seconds for the first case described, 5 seconds for the other one. Otherwise, a green light will remain turned on. Visual alerts, like the one represented in Figure 6.9 are displayed on the screen every minute, if conditions are still being established. If power reaches 80% of the contracted power, an email will also be sent to the user, asking him to try to turn off some non-essential devices; if the condition is again established the next email will be sent 60 minutes after the last one.


Figure 6.9 High power alert screen.

When the apparent power reaches 80% of the contracted power, or if it crosses the desired power value (defined in “Settings” Menu”), LED2 turns on a red light and a sound with frequency 1500 Hz is emitted, with a duration of 10 seconds for the first case described, and 5 seconds for the second one. Otherwise, a green light will remain turned on. Visual alerts, like the one represented in Figure 6.9 are displayed on the screen every minute, if conditions are still being established. If power reaches 80% of the contracted power, an email will also be sent to the user, asking him to try to turn off some non-essential devices; if the condition is again established the next email will be sent 60 minutes after the last one.

According to the European Agency for Safety & Health at Work, the permissible exposure limit for humans is 1000 ppm and, according to the National Institute for Occupational Safety and Health, the immediately dangerous to life or health levels are about 2000 ppm. Thus, whenever LPG concentrations reaches 1000 ppm, a specific visual alert is displayed, LED3 turns red light on and a sound is emitted with a frequency of 500 Hz and a duration of 20 seconds. The red light stays turned on while the condition is being established and the display and sound alerts show up with a frequency of 15 minutes. If this concentration limit is reached, an email is also sent every 60 minutes to the user asking him to check some possible leaks.

If the bill expenditure reaches 50% or 90% of the money defined as a goal to spend during that period, a visual alert is displayed together with a sound emission by the piezo.

- **Information events**

These events are related to the entry in a new tariff period and to an option that allows the user to assess if some non-essential device is turned on (“Leaving Home?” feature): this option has the objective of being used whenever the user wishes to leave the dwelling.

If the normal tariff plan is the one used in the dwelling, LED4 will turn on green and red lights (resulting in an orange colour tone). Alternatively, for the case dual tariff plan, if in a peak period, red light is turned on and and for an off-peak period, green colour is on. Whenever there is the entry of a new tariff period, the Energy Box can have two behaviours: if entering in an off-peak period, the window shown in Figure 6.10 is displayed and a specific harmony is emitted; if entering a peak period, another window is displayed (Figure 6.11), asking the user to avoid some specific household appliances (washing/drying machine…) and a different harmony is emitted.


Figure 6.10 Off-Peak Time information screen.

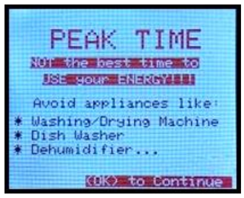


Figure 6.11 Peak Time information screen.

The “Leaving Home?” window is activated whenever tilt sensor is pulled up. This feature will help user to conclude if the current consumed power is within the range of standby power. The maximum power value registered during standby power calculations is used to make a comparison with the current power when tilti sensor is triggered. In case of current power being greater than this maximum registered value, there’s a high probability of having some non-essential device turned on and a message asking the user to turn it/them off is displayed (Figure 6.12) and a sound is emitted for 1 second; if the current power is lower than the maximum value a window telling the user that he probably did not forget non-essential devices turned on is displayed (Figure 6.13); if calculations for standby power are not yet done, a message asking the user to proceed to this step before using this feature is displayed.


Figure 6.12 Leaving Home screen 1.


Figure 6.13 Leaving Home screen 2.

## 6.4 WEB INTERFACE

### 6.4.1 Data upload to a webserver

In order to provide a more detailed energy information to the user, readings of temperature, relative humidity, power, energy, $CO_2$, expenditures and gas level are sent from EBProton to EBNeutron; every 10 seconds this information is sent from EBNeutron to a web server, in which the user has the possibility to visualize readings in real-time and historical data as well. Furthermore, the user can save all of this information in a ".csv" file for later analysis.

To improve an efficient behaviour of the user, an energy report is also available, from which he is able to compare his current readings with the ones from past periods.

#### 6.4.2 Social Sharing (Facebook)

With the purpose of sharing information about the user's consumption, EBNeutron is responsible for sending the user an email, every 24 hours, with the information on the energy consumed, $CO_2$ and accumulated expenditure since the beginning of the bill period. Through Zapier, a tool that allows the automatization of tasks across online apps, the email is forwarded to a group in the social network Facebook, working as a sharing community of consumption progress. The user can have access to this group as well as to 100 tips of energy saving and a file that provides help and documentation on how to use the Energy Box.

## 7 RESULTS

### 7.1 Temperature and humidity profiles

The average temperature inside the dwelling was 29 °C. This high value can be justified by rising temperatures on the location of the dwelling (Lisbon) and by the small dimensions of the kitchen, the place where the Energy Box was installed and where sun heat was not completely scattered during the day, being accumulated at night. The lowest registered value was 26 °C and the highest, 34 °C, which can be justified by the dinner time, where the use of the oven, the stove and even the microwave made the temperature to raise. In fact, the highest values are referred to times when the kitchen was being used, especially during meal times. Thereby, the variations of temperature in the kitchen allowed the prediction of user's behaviour in this space: as a general rule, during workdays and on Sunday, the preparation of breakfast and dinner required cooking or heating appliances; on Saturday, when all the inhabitants were in the dwelling.

In relation to the humidity profile, its average value registered was 45%, the highest 62% and the lowest 29%. The behaviour of this profile can be related to the temperature one, meaning that the peaks of highest values are related to the cooking and heating times.

### 7.2 Apparent power profile

The high value for the average standby power registered, 148 W, is justified by the ON/OFF transitions of the fridge. The lowest value registered in an OFF period of the fridge was 106 W. Analyzing the power consumption profile it is possible to identify a general routine of the inhabitants over a week period: the air conditioner was turned on from 8:00 p.m. to 0:00 a.m. as well as devices to prepare meals like the oven and the microwave; after 0:00 a.m. the dishwasher was turned on (excluding 27th June, where it was turned on after 7 a.m.); the microwave, the toaster and the hair dryer were used after 7:00 a.m.. On Saturday, the dishwasher was used twice (once during the peak period, the other in the off-peak period) and the air conditioner and the washing machine were used during off-peak period; on Sunday, the iron was used during the afternoon.

#### 7.2.1 Household appliances profiles

This section describes profiles of some household appliances used in the dwelling. Once these profiles were simultaneously registered with other devices there is an accumulation of power:

- **Fridge**

The fridge is characterized by ON/OFF periods. The existence of peaks is related to the opening of the fridge door and the period in which some food is being cooled. The lowest power registered was 40 W and the highest (in the plateaus) was about 65 W.

- **Air Conditioner**

This profile has 3 plateaus of about 1560 W: the former is more visible than the other two because the AC compressor needs to work for a longer period to establish the desired temperature. After this temperature is reached power consumption is reduced to approximately 280 W and, after a while, consumption increases again to re-establish the desired temperature.

- **Dishwasher**

The dishwasher is characterized by 3 operation cycles, represented by the 3 plateaus (of about 2200 W) in Figure 7.1: plateau 1 corresponds to the washing cycle, plateau 2 to the rinse cycle and finally, plateau 3 to the drying cycle.

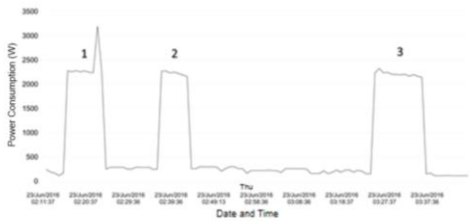


Figure 7.1 Dishwasher consumption profile.

#### 7.2.2 Energy consumption distribution

Figure 7.2 shows the distribution of power consumption counts at peak and off-peak periods, disaggregated by established power limits: values below the standby power (limit A); values equal to or greater than standby power and less than or equal to 80% of the contracted power; values greater than 80% of contracted power (limit C).

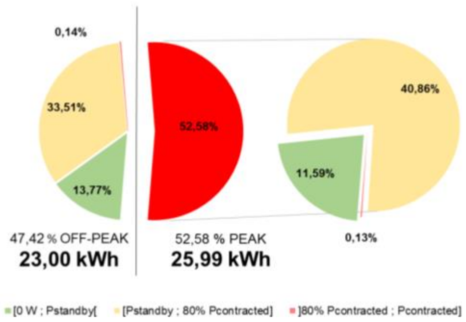


Figure 7.2 Power consumption disaggregated by limits.

47,42% of total counts are included in off-peak periods, where the user spent 26,43 kWh of energy and 52,58% belong to counts in peak periods where the consumption was 29.76 kWh. The counts of limits A and C are approximately the same: in limit A, 13,77% of counts occurred in off-peak periods and 11,59% in peak periods; in limit C, counts in off-peak periods were of 0,14% and 0,13 in peak periods. However, in limit B, counts were far more considerable (40,86% in peak periods and 33,51% in off-peak periods). This discrepancy is due to the use of appliances with a considerable consumption rate, especially in peak periods, at breakfast time (after 7:00 a.m.) and dinner time, the use of the washing machine and dishwasher. Figure 7.3 shows the daily counts distribution, disaggregated by power limits A, B and C and the total energy consumption on each day.

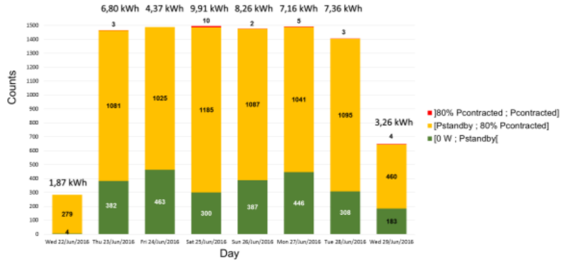


Figure 7.3 Energy consumption per limits of power, per day.

As expected, the greatest consumption takes place at the weekend, when all the inhabitants were at home. On Saturday, June 25th, it was consumed 9,91 kWh (the highest value registered) and on Sunday, 8,26 kWh.

### 7.3 Alerts Events

- Temperature

All the alert events for the temperature were related to temperatures above 27 °C. The average temperature in the dwelling of 29 °C resulted in an excess of these events, with just 6 of the 21 alert events being seen and closed.

- Power

These events were triggered to power values above 80% of the contracted power (2760 W). Among the 20 alerts occurred, 12 were seen and closed by the user; the highest frequency of these alerts occurred on Saturday, June 25th, between 5:21 p.m. and 5:26 p.m. After this sequence of alerts event consumed power was significantly reduced.

### 7.4 Consumptions of energy, $CO_2$ and expenditures

During the week period of testing, the Energy Box registered 48,99 kWh of energy consumed, meaning a production of 9,09 kg of $CO_2$. The consumption forecast for 30 days in this dwelling was about 214,30 kWh, 43% below the national average. In this period of one week, the energy meter of the dwelling registered a consumption of 45 kWh, 8% lower than the one registered by the Energy Box. This deviation is due not only to the associated errors of the CT but also to the fact that energy meter readings does not take into account the reactive power, since it is considered insignificant in the domestic sector. The consumption registered in the energy meter after three weeks without using the prototype was 158 kWh and admitting a linear consumption tax per week, the user ended up consuming 46,84 kWh/week, that is to say, 4% higher consumption when comparing with the week when Energy Box was used.

The inserted tariff prices by the user were € 0,09 and € 0,19 for out of peak and peak periods, respectively, and € 0,16 for normal tariff. Once that the user uses a weekly tariff in his dwelling, the total expenditure during the period of usage of the prototype was of € 10,18. In case of using daily tariff, user would have spent € 10,63 and if nomal tariff was the one used, the expenditures were about €11,20. Although this tariff was not the best during workdays, the high energy consumption during the weekend (when out of peak period has more 21 hours when comparing with daily tariff) caused a smaller increase of associated costs, being thus considered the best tariff type choice for this dwelling.

## 8 CONCLUSIONS AND FUTURE WORK

The Energy Box, through the implementation of an interface that integrates the communication of outcomes using a frequent feedback and supported by visual, luminous, sound and via email alerts, as well as the development of a website that provides energy information in a detailed way, had the objective of guiding the user in his daily consumption, working as a tool to promote changes in his energy consumption habits. This way, it allowed that the actions performed by the user, even though not significant individually, ended up being considered as the ones standard after a short time. These actions modeled with the help of the Energy Box were intended to become a daily habit that in the long term translates into savings in energy and money.

After the prototype testing, the dwelling registered an improvement on efficiency of 4%. This reduction in consumption, despite not being truly reliable once that, besides taking into account a very small amount of testing time, considered the comparison of the average consumption of the period in which the prototype was not used. This increase may be justified with a single day on which an anomalous consumption had occurred. It is also to refer the fact that the consumption of this specific dwelling is more than 40% below national average, which may indicate the low potential of the use of the prototype in this dwelling. It is thus suggested a longer period of testing in dwellings where consumption is larger, having as comparison the values registered in EBElectron in an equal period of time. Regarding the consumption of users during the period of testing, one of the main reasons for the reduction of energy waste was the high frequency of alerts for power that had the objective of inciting the user to turn off some devices if possible.

As future work, there are some improvements that can be applied in the Energy Box design. The frequency of the alerts, despite being crucial in the first few times of use, can create an overload of alert information. In order to solve this problem and to avoid times when the user needs to use high amount appliances, for example, he should be given the freedom to reduce this alert frequency with the implementation of a “confirmation window” at the interface, after these alerts, in which he can be able to delay the next alert occurrence. The same can be applied to temperature alerts, not before being adjusted by the user, according to his comfort temperatures: the Energy Box should have the ability to insert the limits for which the temperature alerts event are triggered. The error associated with the CT can be reduced by replacing the existent burden resistor, $R_3$, by one with a lower tolerance. Furthermore, $Y$ calibration value used in EBElectron programming can be readjusted. Once that the voltage supplied to the dwelling is variable it is recommended the use of a voltage sensor as well to be considered in apparent power calculations. “Leaving Home?” functionality can also be improved by taking into account the ON/OFF behaviour of the fridge, by installing another CT to measure this specific behaviour and thus obtaining the true power consumption neglecting this appliance. In order to reduce the total cost of the Energy Box, some suggestions can be applied: purchase of the same components in cheaper stores; hardware replacement and removal of unnecessary components.

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