# Métodos Experimentais em Energia e Ambiente

## Phantom Hunter

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**Abstract –** *The Phantom Hunter is a very user friendly device and with the use of two buttons, the consumer can eliminate the consumption from devices that are not being used (phantom loads) and can control an alarm system that will emit a warning to avoid exceeding the household's hired power and tripping the circuit breaker. Both the functionalities make the household more energy efficient.*

*In order to assess the efficiency of the Phantom Hunter, the project was divided in two different stages. The first stage prototype records and saves the power consumption with the phantom loads. The final stage prototype or the Phantom Hunter will also record the power consumption without the phantom loads. The method is to overlap both the profiles and estimate the savings associated with the use of the prototype developed.*

*Two case studies were carried out. The first one was in Mouraria. However the phantom loads present in the house were not sufficient for the efficiency test of the Phantom Hunter. The second case study was carried out in a household in Linda-a-Velha. This house was suitable for the test of the final stage prototype. By overlapping both the profiles obtained, the theoretical monetary savings per year were calculated and the environmental impact was assessed. The calculations reveled a potential saving per year of 45€ and a reduction of approximately 131347 tons of $CO_2$ if every national household used the Phantom Hunter in all house divisions.*

**Keywords – Phantom Hunter; phantom loads; energy efficiency; household; monetary savings**

### I. INTRODUCTION

Nowadays, energy efficiency is one of the main concerns all over the world. It is a consequence of the energy conversion devices efficiency and it is influenced by the consumers' behavior. Energy efficiency has a large effect in economy and in the environment.

The awareness of this issue in Mouraria was the main challenge of this project. The keywords used to raise the awareness of the population were the potential significant monetary savings by being more energy efficient.

The main goal was to create a user friendly prototype that could raise the households energy efficiency and promote significant monetary savings per year, which can be achieved by eliminating phantom loads.

Phantom loads refer to parasitic power consumption from devices in standby or off mode, that are not being used. These kind of loads have major expression during the periods of inactivity of the house, e.g., when all the inhabitants are sleeping or out of the house.

This kind of consumption is responsible for an incredible amount of energy consumption among domestic consumers. In France, in 2000, one study found that phantom loads accounted for 7% of total residential consumption [1]. In UK, another study, in 2004, found that phantom loads on electrical devices accounted for 8% of all British domestic power consumption [2]. Researches about this subject have been done in a lot of countries, and according to an estimate of the International Energy Agency (IEA), the total standby power demand of residential sector in industrialized countries amounts 15 GW. Brahmanand Mohanty, [3], made an approach to estimate the fraction of phantom loads in total electricity consumed by each OECD country, which for Portugal reaches approximately 2% of national electricity.

The Phantom Hunter is a simple device and from the use of two buttons, the consumer can eliminate the phantom loads of the devices that are not being used and can control an alarm system that will warn the consumers to avoid exceeding the household's hired power and tripping the circuit breaker. Each button controls a functionality.

### II. MATERIALS AND METHODS

The materials used to build the Phantom Hunter are the following:

- Breadboard
- Arduino Uno REV3
- 12V Power Supply
- Jumpers
- Resistances
- Capacitor
- Transistor
- LED's
- Non-invasive current sensor
- Relay
- SD Shield for Arduino
- SD card
- ON/OFF buttons
- Electric socket
- Buzzer
- Junction box

The program used was the Arduino software, available at the Arduino website.

The Phantom Hunter was constructed in two phases. The first stage prototype consisted in the Arduino UNO REV3, the non-invasive current sensor, the SD shield, a SD card and the electric circuit needed to feed the current sensor. The goal of this prototype is to measure the power being consumed in the house (with the phantom loads) and save it to the SD card for post analysis. The second or final prototype used all the materials described before. The consumption from the house (without the phantom loads) was also recorded to the SD card. The method is to overlap both profiles and assess the Phantom Hunter efficiency, by calculating the reduction of the power that is being consumed in the household during the inactivity periods. For the savings estimate both the prototypes must be installed during the same amount of time and at the same conditions. For this project, a 48h period was established and the prototypes were installed during working days.

## III. CONCEPT

As stated before, the main goal of the Phantom Hunter is to eliminate phantom loads. These parasitic loads have a negative effect when the devices are not being used and keep consuming electric power. The devices are not being used when the house is empty or while all the inhabitants go to sleep, which are referred as inactivity periods.

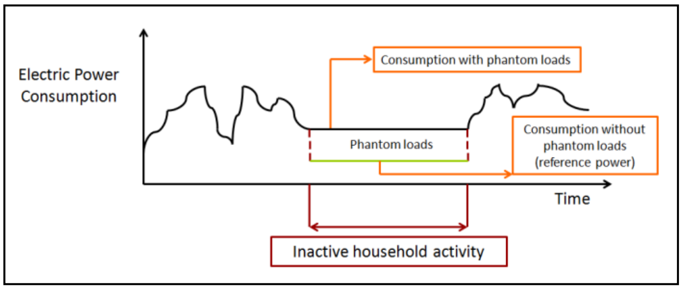


Figure 1 - Electric power consumption profile

In Figure 1, a power consumption profile is illustrated. The power consumption during the inactivity periods is approximately constant and incorporates the phantom loads. The main concept is to eliminate these loads and reduce the power that is being consumed to a value denominated by reference power, which can be done by cutting off the current in the electrical devices. The Phantom Hunter can also warn the inhabitants when the power that is being consumed is near the maximum power (hired power) in order to avoid exceeding the household's hired power and tripping the circuit breaker.

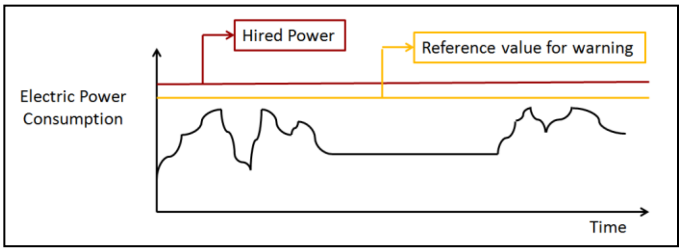


Figure 2 - Electric power consumption profile

In Figure 2, the red line represents the maximum power that can be consumed and the yellow line the reference value to warn the inhabitants and alarm them to shutdown some devices in order to avoid the tripping of the circuit breaker.

## IV. FIRST STAGE PROTOTYPE

As referred before, the only function of the first stage prototype is to measure and save the power that is being consumed in the house to a SD card, in order to understand the household behavior and to quantify the phantom loads.

### *A. Materials*

The first stage prototype is represented in Figures 3 and 4.

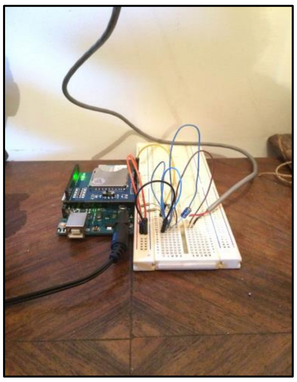

Figure 3- First stage prototype

Figure 4 - Non-invasive current sensor

The materials used were the following:

- Breadboard
- Jumpers
- Resistances
- Arduino UNO REV3
- 12V Power Supply
- SD shield
- SD card
- Non-invasive current sensor
- Capacitor

### *B. Costs*

Some materials were bought online and others were found at the authors' houses. The costs are represented in Table 1.

Table 1- First stage prototype costs

| Material | Cost (€) |
|---|---|
| Arduino UNO REV3 | 20 |
| SD shield | 6.50 |
| SD card | 6 |
| Non-Invasive current sensor | 9.95 |
| Breadboard | 3 |

Total costs were 45.45€. The jumpers were made out of standard electric wire. The resistances and the 12V Power Supply were available at the authors' houses.

### C. Methodology

Figure 5 illustrates the electric circuit to feed the current sensor.

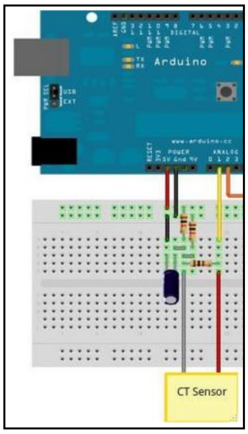


Figure 5 - Current sensor electric circuit

Two 470kΩ resistances, a 18Ω resistor, a 10μF capacitor and 6 jumpers were used to build the circuit. The capacitor is used to reduce the noise in the readings and the resistances to reduce the 5V Arduino output to 2.5V.
The current sensor is analogic and features a decent accuracy for the highlighted function. The maximum current intensity that it can measure is 30A, which is more than enough for a residential application.
The sensor must be placed in the phase wire that reaches the house electrical system. In Figure 4 electrical panel case was the green/yellow wire. If the sensor is misplaced, then it will only read the current intensity consumption in a certain room.

### D. Expected Results

The expected results are a .txt file in the SD card with two columns. The first one representing the current intensity consumption and the second the apparent power that can be calculated from the following equation:

$$P_{apparent} = 230 \times I \text{ [W]} \quad [1]$$

The 230 factor corresponds to the voltage available in the house electric grid.

Figure 6 shows the expected results from the first stage prototype.

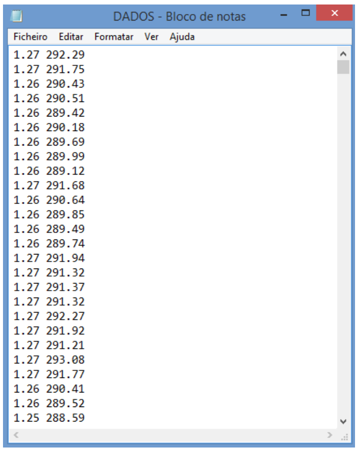

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Figure 6 - Text file with the current intensity and apparent power values

Each row corresponds to a different time value. A 30 seconds interval (between consecutive readings) was implemented. The first stage prototype was installed in the test household for two days (48h), which totals 5760 readings (rows).

## V. FINAL STAGE PROTOTYPE - PHANTOM HUNTER

The Phantom Hunter is an evolution of the first stage prototype by incorporating all the other materials referred before in this report.

### A. Materials

The additional materials used were the following:

- 12V Relay
- 3 red LEDs - 1x ϕ20mm and 2x ϕ5mm
- 1 green LED - ϕ5mm
- Buzzer
- 2 ON/OFF buttons
- 1 multiple electric socket
- 1 Transistor
- Resistances
- 1 Junction box

The Phantom Hunter is represented in Figure 7.

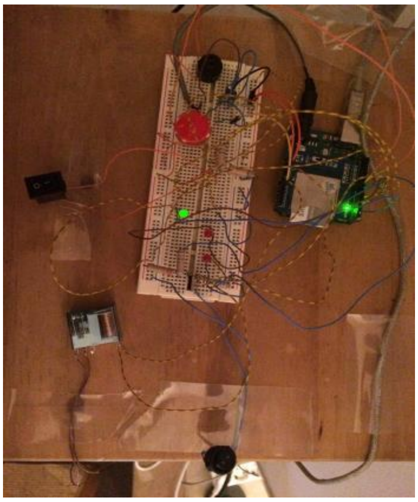

Figure 7 - Phantom Hunter top view

### B. Costs

The costs of the additional materials bought are represented in Table 2.

Table 2 - Additional costs for the construction of the Phantom Hunter

| Material | Cost (€) |
|---|---|
| 2x ON/OFF buttons | 2 |
| 12V Relay | 8 |
| 1 Multiple electrical socket | 5 |
| 1 Red LED (ϕ20mm) | 1.5 |
| 1 Buzzer | 2 |

The total cost of the additional materials is 18.5€. The total cost of the project (first stage and Phantom Hunter) was 63.95€.

### *C. Methodology*

The electric circuit to feed the current sensor is the same as represented in Figure 5. The ON/OFF buttons work as inputs for the system and need a 10kΩ resistance. The 12V relay (which acts like a switch) controls the multiple electrical socket, cutting off or letting in the current in the electrical socket. The relay is controlled through the transistor that is controlled by one ON/OFF button. The transistor is connected to a digital port, like all the LEDs, the buzzer and the two buttons.

The junction box connects the relay with the electrical socket. The outer layer of the socket wire and the phase wire must be cut off. Then, the relay wires and the two parts of the phase wire are connected through the junction box.

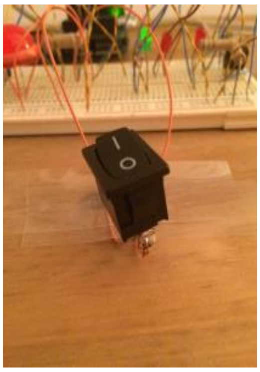

Figure 8 - ON/OFF button for the phantom loads

Figure 9 - ON/OFF button for the alarm system

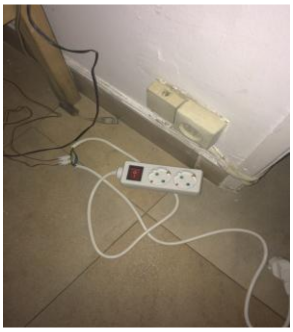

Figure 10 - Multiple electrical socket controlled by the 12V Relay

The green LED, illustrated in Figure 7, is just to make sure that the Phantom Hunter is working properly, so it is supposed to be on all the time.

The ɸ5mm red LED, on the top, in Figure 7, gives information to the consumer if the Phantom Hunter is on or off. If it is on, the red LED is off and if the Phantom Hunter is off, then the red LED is on.

The ɸ5mm red LED, on the bottom, in Figure 7, compares the power that is being consumed (through the current sensor) with a specified value. This value corresponds to the average apparent power, calculated from the first stage prototype phase. If the house is consuming more than the specified value, the LED is on.

Since the Phantom Hunter is connected to the multiple electrical socket through wires, it can only be applicable in one room, so the devices that charge phantom loads must be connected to the socket presented in Figure 10.

If the button that controls the phantom loads (Figure 8) is on (position I), the electrical socket is on and current is flowing to the devices (Phantom Hunter is off). If the button is pushed (position 0) then the transistor communicates the input to the relay that turns off the electrical socket, cutting off the current and the devices stop consuming electricity (Phantom Hunter is on).

The round ON/OFF button (Figure 9) controls the alarm for the overload situations.

If the button is off (position 0), the alarm system is off and it will not send a warning when the power that is being consumed reaches a critical value.

The critical value is defined through the hired power, which can be known through a monthly electric bill. Obviously, the critical value must be lower than the hired power and must have into account the device that consumes more power to avoid the circuit breaker tripping, if that device is turned on.

If the alarm system button is on (position I) and if the power that is being consumed is equal or higher than the critical value, the ɸ20mm red LED, in Figure 7, starts blinking and the buzzer starts to whistle.

The alarm does not stop while the consumption is equal or higher than the critical value. It will shutdown if the consumption gets bellow the critical value or if the consumer turns off the alarm system by pressing the button to position 0.

As the first stage prototype, the Phantom Hunter also records the power that is being consumed to a SD card in order to plot the consumption without phantom loads with the use of the prototype.

The Phantom Hunter was installed for a 48h period.

Table 3 summarizes the Phantom Hunter operability.

Table 3 - Phantom Hunter operability

| Switch | Position | State | Condition | Action |
|---|---|---|---|---|
| Phantom loads (Figure 8) | 0 | Phantom Hunter is on | - | Current does not flow to the devices |
| | I | Phantom Hunter is off | - | Current flows to the devices |
| Overload (Figure 9) | 0 | Alarm system is off | - | - |
| | I | Alarm system if on | If power that is being consumed ≥ critical value | Buzzer starts to whistle and the ɸ20mm red LED blinks |

*D. Expected results*

The expected results are a .txt file, equal to the file illustrated in Figure 6. With the same conditions as the first stage prototype, the .txt will have 5760 rows.
It is also expected that the power consumed during the inactivity periods is lower than the power consumed recorded by the first stage prototype.
About the second functionality of the Phantom Hunter it is expected that the household's hired power is not exceeded and that the circuit breaker does not trip.

## VI. RESULTS

Two case studies were carried out to test the Phantom Hunter efficiency. One at Mouraria, in Nuno Franco's house and another at Linda-a-Velha, in Ana Ferro's house.

*A. Case Study A - Mouraria*

*i. First stage prototype*

The consumption profile represented in Figure 11 was obtained from the first stage prototype.

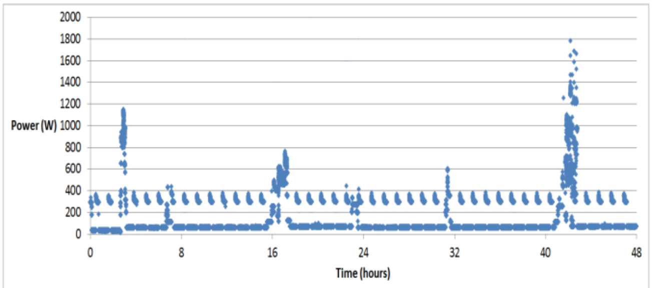

Figure 11 - Power consumption from first stage prototype for case study A

The peaks in Figure 11 represent the devices peak consumption when turned on. The profile only accounts four activity periods, corresponding to the four peaks. The small peaks during the inactivity periods are due to the fridge consumption.
However, after a close inspection of the consumption during the inactivity periods, the power that is being consumed is very low, which means that the house has a very small amount of phantom loads.
After studying each existent device in the house, the only devices that charge phantom loads are:

- Alarm clock
- TDT antenna
- House router

As the alarm clock could not be turned off, only two devices left for further analysis, since the fridge consumption is not considered parasitic. Table 4 shows the power consumed by the two devices.

Table 4 - Household devices consumption for case study A

| Device | Current intensity [A] | Apparent power [W] |
|---|---|---|
| TDT antenna | 0.012 | 2.76 |
| House router | 0.004 | 0.92 |

The total phantom loads in the house are 3.68W.
Since Nuno Franco's electrical devices are relatively old, they only have an on or off state, which do not consume when off. With the low phantom loads value obtained, the theoretical savings were not significant, turning the house not suitable for the Phantom Hunter test.

*B. Case Study B - Linda-a-Velha*

*i. First stage prototype*

The consumption profile represented in Figure 12 was obtained from the first stage prototype.

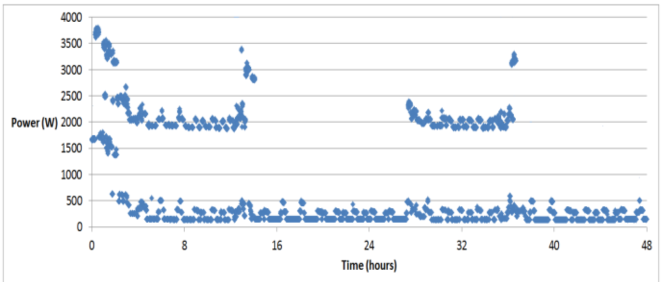

Figure 12 - Electrical power consumption from first stage prototype for case study B

The activity periods are easily identified, since they correspond to the periods when two levels of power consumption can be seen. This two level profile consumption are due to the heaters that are on, to reach a certain temperature and then turn off (when a certain temperature is reached).
Approaching the inactivity periods, the consumption obtained in Figure 13 corresponds to the time period of 15 to 17 hours since the prototype installation (other time period could be used).
Again, the higher power is due to the fridge consumption plus the phantom loads and its power consumption is approximately 150W.

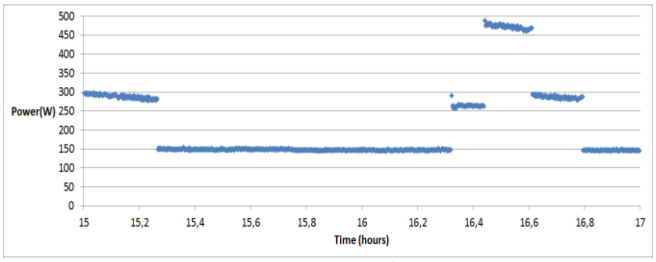

Figure 13 - Inactivity periods for case study B

After an inspection on the house electrical devices, it was concluded that it is in the living room where the phantom loads are maximum. Table 5 represents the devices and the phantom loads that the devices consume.

Table 5 - Living room devices consumption for case study B

| Device | Current intensity [A] | Apparent power [W] |
|---|---|---|
| Television | 0.04 | 9.2 |
| Channel service | 0.04 | 9.2 |
| Stereo | 0.14 | 32.2 |
| Gaming console | 0.016 | 3.68 |

The total phantom loads at the living room are approximately 50W.
The power at the living room is significant, which makes this house suitable to test the Phantom Hunter efficiency. It was applied at the living room.

*ii. Phantom Hunter*

After the Phantom Hunter application, the consumption profile obtained is represented in Figure 14.

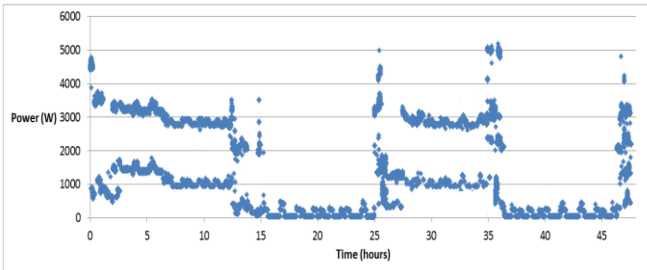

Figure 14 - Power consumption profile recorded by the Phantom Hunter

The consumption profile is similar to Figure 12, presenting the two level profile structure. Figure 15 was obtained, by overlapping both the profiles during the inactivity periods.

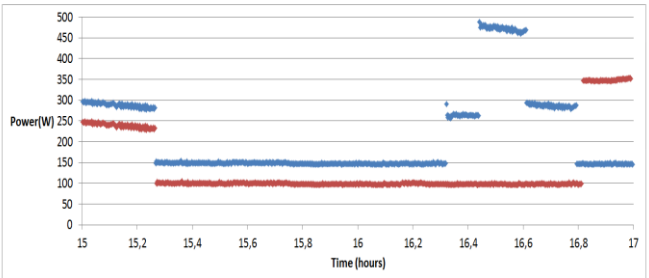

Figure 15 - Both the consumption profiles for case study B

The red lines, in Figure 15, represent the consumption from the Phantom Hunter and the blue lines, in Figure 16, from the first stage prototype. More considerations from the results showed in Figure 15 are presented bellow.

## VII. DISCUSSION

As referred earlier, the total phantom loads power at the living room, where the Phantom Hunter was implemented, are approximately 50W.
Analyzing Figure 15, the difference between both profiles is approximately 50W. This means that the Phantom Hunter achieved an efficiency of 100% in removing the phantom loads at the living room.
Ana Ferro lives alone and she is an active worker, spending, on average, 8h out of home. Assuming 8h of sleep, the total inactivity periods per day are 16h. If during this period the Phantom Hunter is on, the total saved energy per year can be calculated by:

$$E_{saved} = 50 \times 16 \times 365 \times 10^{-3} = 292 \text{ kWh} \quad [2]$$

Assuming a fixed daily price for electricity of 0.1528€/kWh [4], the annual savings can be calculated by:

$$Annual\ Saving = 292 \times 0.1528 \approx 45€ \quad [3]$$

The actual savings will be lower because of the assumption that the devices will be shutdown during 16h, which could not happen during the weekends. If Ana Ferro's electrical system uses bi-daily or tri-daily price tariff for electricity, the estimate is more complex and the annual saving would be lower.
Due to the high price of wireless connections between the electrical socket and the Arduino, the Phantom Hunter could only be applied to one room.
Ana Ferro's house also has a low hired power, which makes her circuit breaker to trip frequently, mainly due to heaters. However, with the application of the Phantom Hunter, Ana Ferro's circuit did not trip. She reported that the alarm system went on a few times and she used the warning to shutdown some electric devices.
Although the main subject of this project is the reduction of phantom loads and consequentially increase the household energy efficiency, the Phantom Hunter has a deep effect in the environment.
As referred earlier, phantom loads can reach 2% of national electricity consumption [3]. Using the National Energy Balance (BEN - Balanço Energético Nacional) of 2002 [5], total electricity for the residential sector was 978849 toe (tons oil equivalent). This means that the national phantom loads occupied in that year:

$$978849 \times 0.02 = 19576.98 \text{ toe} \quad [4]$$

which

$$1 \text{ GWh} = 86 \text{ toe} \quad [5]$$

Then the total GWh wasted are:

$$\text{GWh}_{wasted} = \frac{19576.98}{86} = 227.64 \quad [6]$$

Using a conversion factor of 0.215 kgoe/kWh from [6] for the primary energy used, the amount of energy needed to produce the wasted electricity is:

$$primary\ energy_{wasted} = 227.64 \times 10^{6} \times 0.215 \times 10^{-3}$$

$$= 48942.6 \text{ toe} \quad [7]$$

Using the emission factor of 2683.7kg$CO_2$/toe from [6], then the quantity of emissions that could be avoided if all the households in Portugal used the Phantom Hunter would be:

$$CO_2 \text{ Emission} = 48942.6 \times 2683.7 \approx 131347 \text{ tons} \quad [8]$$

The value of emissions that could be avoided is very high, since $CO_2$ is one of the main green house gases.

## VIII. COMMUNITY FEEDBACK

In Mouraria the feedback was mixed. Some people, like Mouraria's priest and Nuno Franco, evaluated the project as a valuable idea and great concept. However, others do not believe in a possible saving, mainly due to the electrical companies, since electric bills are made out of monthly estimates. Some members of the population were already aware of the phantom loads concept and they are efficient

consumers cutting off the current of the devices that are not being used.
To get a global feedback, some interviews were carried out with other families and the feedback was positive. People were impressed with the percentage that the phantom loads occupy in their electric bills and the monetary value that can be annually spared with the use of the Phantom Hunter.
Consumers were also impressed with the overload functionality of the Phantom Hunter. Particularly, in a house where an old-aged woman lives that has a low hired power, which makes the circuit breaker to trip frequently. When the circuit breaker trips at night, the woman needs to shutdown some devices in the dark, which can be dangerous. Some families even requested a prototype.

## IX. BUSINESS PLAN

To finance the production of the prototype, several sponsorships are needed. Part of the money would be to implement wireless connections to the existing prototype, so that the Phantom Hunter could be applied in all house divisions. The majority of the money would go to advertisement. The product is intended for all households, so distributors through the world would be needed.
In order to improve the image of the Phantom Hunter, a design study should be carried out, making the prototype more appealing to the public.
The construction price of the product would be much lower than the prototype total cost. The Arduino could be replaced with integrated circuits that cost approximately 1€. All the other components, ordered in large quantities, make the construction price low (in the 20-30€ range).
The sale price of the product must take into account other similar devices, *e.g.* the SmartGalp Kit that costs 180€. The sale price of the Phantom Hunter would be, approximately, 100€, making the profit margin significant.

## X. ACKNOWLEDGMENTS

We would like to thank Nuno Franco, for the fieldtrip at Mouraria and for allowing the use of his house for the prototype test.
We would also like to thank all the teaching assistants, including Diogo Henriques for the constant support and availability in sorting out all our doubts.
An important thanks to the Mouraria members for the presence in our presentation for the stakeholders.
And finally, thank you Professor Manuel Heitor for allowing the development of this project, for your availability shown throughout this work and for the challenge proposed in this course.

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