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# Energy Monitoring Systems

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By

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## Declaration

I declare that I am responsible for the work in this report, that the original work is my own except as specified in acknowledgements, footnotes or in references, and that neither the dissertation nor the original work contained herein has been submitted to this or any other institution for the award of a degree or for any other purpose.

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Eduardo Leite Simões e Silva

## Dedication

I dedicate this work first to my family, for all the support that they give to me since I decided to study abroad. My sister Mariana, who I love so much and I really missed her during my staying in Ireland. She is the person who always supports me, even when she is far from me. My dad and my mom, José Eduardo and Carmem, without their education I would never be where I am now. They always believed me, since I was a little child playing with LEGO, and also when I had the crazy idea to study one year in Ireland.

I also must thank my girlfriend Camila for support me in the most difficult moments of my staying in Ireland, she always knows how to calm me down and she always reminded me why I chose to come.

I would like to thank my supervisor, Frank Doyle, for the helping with the project and also the English, he trusted in my work and in me for the realization of the project.

I cannot forget Brazil and CAPES, which provides to me all the possibility of studying abroad, and learn with all the different experiences and cultures.

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## **Abstract**

The project will utilize data loggers to acquire data from an Air Source Heat Pump (ASHP) located in a house, then the data will be analysed by a programming designed using Matlab, which will show to the researcher the coefficient of performance and also the power utilized by the ASHP. The program will also return to the user the relatives graphs to each data acquired. In the end, all the results will be discussed to conclude if the ASHP it is a good way to heat water on a house and why monitoring systems is an excellent subject to study nowadays.



## 1 Introduction

The project aim is to explore and learn the different techniques to monitor and measure, a particular equipment response to the environment.

Nowadays industries, even the biggest ones, waste a lot of energy because of the small machinery. The most part of these machines, for being less important than the biggest ones, they don't have the proper attention, and the sum of all the energy wasted in each small machine, results in the most of cases in a huge consumption of energy.

Due the above problem, the project is based on an Air Source Heat Pump (ASHP). Measurement techniques will be applied at the ASHP, generating a great amount of data, which will be implemented on a program (Matlab), which will create charts and tables in order to facilitate the analysis of the ASHP. After analyse all the data, charts and tables, it will be possible to know if the ASHP is working properly or not.

Learning these techniques and applying them in a small system, is the most reliable way to change wasting of energy in small machines, because all the problems and mistakes that could happen on a factory, will be fixed when the ASHP it is being tested. So, all the improvements will be done before applying the techniques in a large company.

Given the directions, the project objectives can be subdivided as follow.

1. Study the data loggers;
2. Monitor an Air Source Heat Pump (ASHP) to identify the Coefficient of Performance (COP);
3. Analyse the acquired data from ASHP using Excel and Matlab

The following chapter, Chapter 2, provides an introductory background to the project. It highlights the various systems and the advantages and limitations of each.

## 2 Background

The background will introduce to reader the project theory as a whole, what are the ideas behind the project tests.

### 2.1 Data Loggers

#### 2.1.1 Definition

A data logger is an electronic device with the task to automatically record, monitor and measure, electrical or physical parameters over a period of time. Allowing conditions to be documented, validated and analysed after the acquisition. A huge amount of devices can log and measure data, from a very basic, with single measurement component, to very complex system.

A Data Logger is commonly developed to contain a sensor to acquire the information from the environment, and a chip to store it. Then, the idea is to transfer the stored data to a computer for analysis. The process is presented on the following diagram (figure 2.1).

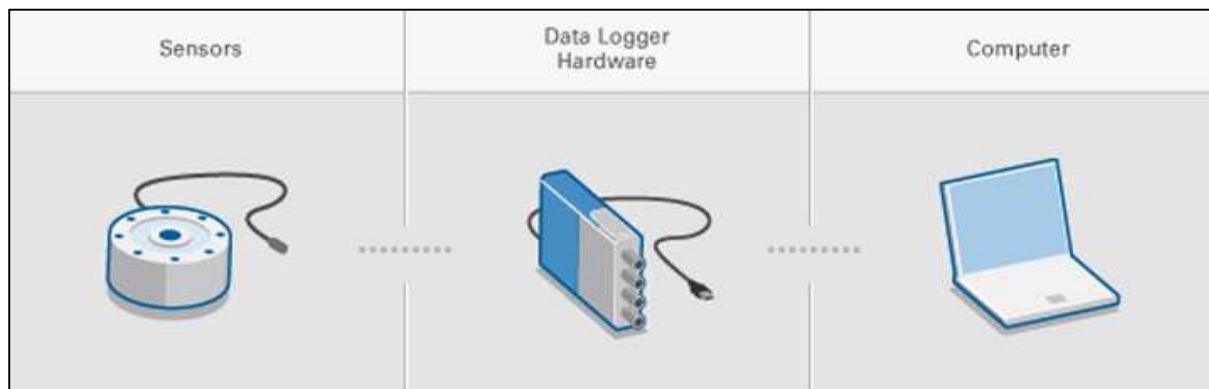


Figure 2.1 - Data Logging Process

The project requires a Data Logger to acquire the needed information, to select the correct Data Logger, the following considerations should be revised.

### 2.1.2 Measurement Types

Different data loggers, could measure different types of parameters and signals including the following.

Temperature – (K, °C, °F)

Power – (W)

Voltage – (V)

Current – (A)

State – (On, Off, High, Low)

Consequently, the data logger selected, must be correspondent the parameter which you wish to measure.

### 2.1.3 Channel Count

Some systems require not only a single measurement, but multiple channels and types of measurements. As a result of these requirements, there are a lot of different data loggers with distinct configurations available, as following.

- **Single-Channel Data Loggers**

In their majority, the single-channel data loggers are short in size with a bus powered port, so you do not need an external power supply to plug them into a computer.

- **Multichannel Data Loggers**

The Multichannel data loggers are not smaller than the single-channel, but a multichannel type, provides a great amount of voltage channels, temperature, state, etc. and also It can connect to your computer through wireless, Ethernet and USB. The communication available for you will depend on the chosen equipment category.

- **Modular Data-Logging System**

Using a modular data-logging system, you are able to mix and match modules for distinct measurement types to form a personalized data-logging system.

Simplifying, the modular Data-Logging System will operate as a base, where you can receive and store the data coming from the single-channel and multichannel devices, and also programme these devices connecting your PC to the Modular Data-Logging System only, saving time and therefore money.

#### 2.1.4 PC-Based Versus Stand-Alone

Some of the classical data loggers are just a small box with instruments that measure signals from the environment, convert these ones to digital data and for last store the information to internal memory. Using this method, all the data acquired must be physically transferred to a computer for analysis, visualization, and permanent storage.

But on the other hand, PC-based data loggers are the combination of a PC and a data acquisition device. Thus the PC is already one part of the whole system, the data logger can improve its performance using the PC processor, display, hard drive and I/O bus. The advantages of this system over the classical are presented below.

- Real-time visualization
- Inline analysis
- Terabytes of storage
- Continuous network connectivity

#### 2.1.5 Bus Type

The communication between a data logger and a PC is through the PC's peripheral bus. But, to select the right data logger, is crucial to understand the different types of buses.

**USB** - USB is easier to use than many other PC buses because computers automatically detect the devices.

**Ethernet** - Ethernet requires more configurations and networking knowledge than USB, it provides longer-distance measurements up to 100 meters or further if used with a hub, switch, or repeater.

**Wireless** - Wireless technology extends measurement capabilities to applications where cables are inconvenient or impractical. It can also dramatically reduce costs by eliminating cables and installation time.

## 2.2 Types of Data Loggers

Data loggers are designed for use in specific applications, such as pharmaceutical and life science, process monitoring, environmental monitoring and autoclave temperature data logging. Each device is programmable and can be re-programmed and used for many years.

Knowing the idea of the project, which is to acquire data using a data logger, and then analyse the data via programming, the data logger must be very well chosen, and four options seem to be the most indicated for the project.

The options are listed below and each one will be analysed too finally in the end the most suitable data loggers will be chosen to integrate the project.

### 2.2.1 EL-USB-2

The EL-USB-2 is a temperature and humidity USB data logger. This data logger can measure and also stores on the intern memory up to 32,000 relative humidity and temperature readings. The operation range of the data logger is 0 to 100% RH and -35 to 80°C.

One of the positive points of the EL-USB-2 is the easy method of setting up the logging rate and start time, and also downloading the data stored by just plugging the module into a PCs USB port and running the program software. The data logger is supplied with a lithium battery, which allows logging for a year.

However, the project requires a power meter, and this data logger does not have a sensor to acquire the power consumed by the ASHP and also is too big to fit on the appropriated places. The price of the EL-USB-2 is 90 Euros.



Figure 2.2 – EL-USB-2

### 2.2.2 iButton

The iButton data loggers are small packs with the form of a Button, which can measure temperatures between -40 to 85°C, and with the advantage of fit in probably all the required places. The data logger is also supplied with a normal small battery, allowing logging for more than a year.

On the other hand, the iButton have a smaller intern memory compared to the others data loggers, can only measure temperature and also when the acquired data need to be logged to a PC using USB, the iButton requires a component called iButton Adapter.



Figure 2.3 - iButton

The iButton costs 30.50 Euros and the USB adapter 27.80 Euros.

### 2.2.3 Low Cost Board

After analyse the last two options of data loggers, one idea came in mind, design a Low Cost Board with all the project requirements.

The board is supposed to have the following components.

<b>Eduardo - "Monitoring System for a Domestic Air Source Heat Pump"</b>					
<b>Materials</b>	<b>Quantity</b>	<b>Description</b>	<b>Inputs</b>	<b>Output</b>	<b>Price (€)</b>
Processor	1	PIC16F88	-	-	4,14
Temperature Sensor	2	(Available on the Lab)	Analog	-	-
Real Time Clock (RTC)	1	DS1302	SPI	-	3,69
Data Logger - SD Card	1	74VHC125	-	SPI	2,82
				<b>Total</b>	<b>10,65</b>

**Table 1 – List of Components**

The processor will coordinate the operations in the board, the temperature sensor will acquire the environment temperature, the clock is used to monitor the acquisition of data, and the board will store all the data acquired on SD Card. The board will also have a power meter, to compare all the energy spent on ASHP.

But even after the conclusion that a low cost board can be an interesting idea, the project deadline, the inadequate laboratories and the no familiarization with the board production techniques caused the abandonment of the idea of a low cost board.

On chapter 3 the characteristics of the board and all work done will be described in greater detail.

### 2.2.4 Emon System

The Emon system was the last analysed data logger, and it is a system composed by a central station, which will acquire and also receives data from the connected nodes, these nodes will acquire and store data, to then send all the information directly to the central station.

After the acquisition of all the data, the central station will send this stored information to a PC by Ethernet or USB.

#### 2.2.4.1 Emon Tx V3

The emonTx V3 is a Wireless Energy Monitoring Node designed for monitoring temperature and also electrical power. EmonTx uses a microcontroller which runs standard Arduino sketches, given the user the possibility of customise and upload a new code via Arduino IDE and a USB to UART cable.



Figure 2.4 - emonTx

EmonTx data is transmitted via radio to an emonBase ( explained later on).



### 2.2.4.2 Emon Pi

The emonPi is an open-hardware Raspberry Pi and Arduino based, designed to monitor temperature, humidity and electrical power using the sensors connected to it.



Figure 2.5 - emonPi

EmonPi is also the base of the Emon system described above, emonPi is a web-connected base-station, which will receive data coming from the other emonTx, sending then, all the data to a server located on web, for logging, processing and graphing.

Another advantage of emonPi is the easy setup and installing, including that emonPi can store all the data on an internal 8GB SD card for many years. However emonPi and emonTx needs a source of energy during all the operation, contrary to the other data loggers analysed and the cost of the system is high 160 Euros for emonPi and 60 Euros for emonTx (the temperature, humidity and power sensor are included).

Below, is seen a Flowchart describing how the emon system works.

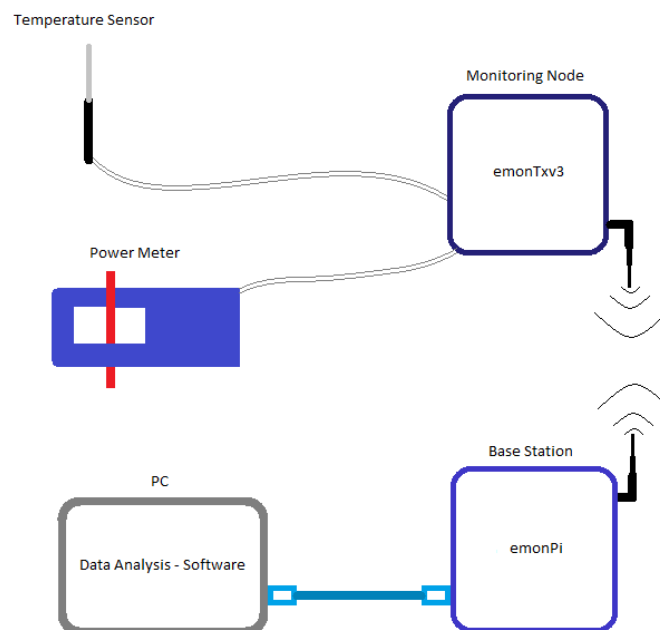


Figure 2.6 – Emon system operation

### **2.3 Air Source Heat Pump (ASHP)**

An Air Source Heat Pump (ASHP) system utilizes a renewable and natural source of energy, the air. The ASHP basically uses the energy provided by the air to create heat, and then uses the heat to warm up the building or in the most cases a house. In other words, the heat pump moves the heat, instead of converting it from a fuel, as the mostly common systems do. Therefore it provides a renewable method of heating a building

The ASHP can provide efficient heating and also cooling for a house. When correctly installed and well configured, an ASHP can easily produce one-and-a-half to three times more heat energy to a house than the electrical energy consumed by the equipment. This information was proved by the Northeast Energy Efficiency Partnerships which found that the annual savings of an ASHP are over 3,000 kWh when related to electric resistance heaters, and 6,200 kWh when related to oil systems.

### 2.3.1 Operation

An ASHP system consists of three components primarily a compressor and two coils made in mainly of copper tubing, which are surrounded by aluminium helping in the heat transfer. Typically the coil located indoor is called a condenser, and the coil located outside is called an evaporator. When the ASHP is in heating mode, the refrigerant liquid in the evaporator extracts all the heat from the air and evaporates into a gas (the name evaporator comes from this process). The compressor sends the gas through the condenser which releases all the heat to the house, condensing back the refrigerant into a liquid. Then the liquid pass through an expansion valve and returns to the evaporator, after this the process repeats.

The following flowchart (figure 2.7) shows how an Air Source Heat Pump works.

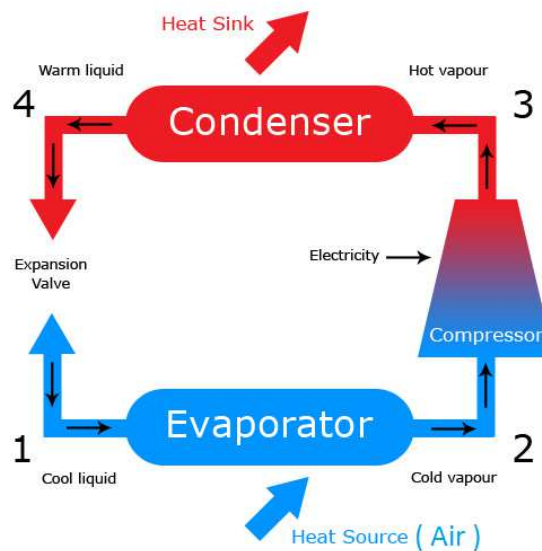


Figure 2.7 – ASHP operation

### 2.3.2 Advantages and Disadvantages

When an ASHP is installed, the following advantages and disadvantages are noted.

- An ASHP could generate less CO<sub>2</sub> than the traditional heating systems;
- The ASHP is cheaper than a ground source heat pump (GSHP) and also much simple to install, however the GSHP may have a higher efficacy compared to the ASHP;
- The ASHP can provide hot water, heating, and also can be utilized for air conditioning in hotter seasons, requiring just a little maintenance;
- However, the ASHP requires a place to stay in the garden for the external evaporator unit.

### 2.3.3 Pump

The pump installed on the system is a Priux home 80-25/180 which is pumping approximated 4500 liters per hour or 1.25 liters per second. These values will be used to calculate the CoP.



Figure 2.8 – Priux home 80-25/180

### 2.3.4 CoP

The Coefficient of Performance (CoP) is basically a simple ratio of the heating provided by a source (Air Source Heat Pump) to the electricity consumed.

The CoP therefore could change during the whole year. For example in the summer the external air is already warm, therefore the ASHP will not require a large quantity of energy to get up to a good temperature, so the CoP value will approach 4 or more. But, when the winter months comes, the opposite is true, the ASHP will require a lot more energy to get the heat up to an appropriate temperature, therefore the CoP may fall to values around 2.5.

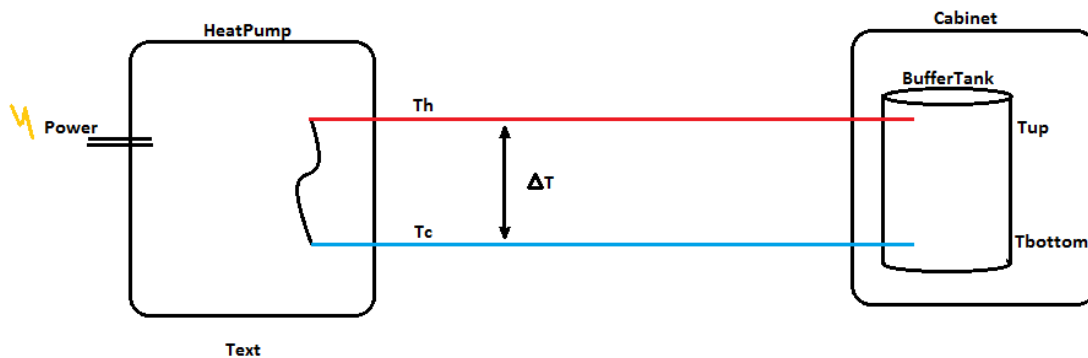


Figure 2.9 – ASHP values for COP

The project will use the following CoP equation, which is related the above flow chart (figure 2.9).

$$CoP = \frac{\text{Heat Energy}}{\text{Electrical Energy}} = \frac{\Delta T \cdot Q \cdot c}{E \text{ (kWh)}}$$

Where,

T = Temperature

$\Delta T$  = Temperature difference (DeltaT)

Q = Flow rate (1.25 l/s)

c = Fluid specific heat capacity (3.782 kJ/Kg.K)

E = Electrical Energy

The flow rate is given by the pump Priux home 80-25/180 which is being utilized on the system.

## **2.4 Data Analysis**

One of the most important procedures after the data acquisition is the interpretation of the data. There are a lot of different ways to process all the granted information, for example using graphs, charts or comparing to other knowing results.

In this project the data will be acquired by the data loggers, to be processed by PC software, which will return the results and also the wanted values of CoP.

### **2.4.1 Software**

To analyse the data, two software will be used Excel and Matlab.

#### **2.4.1.1 Excel**

Excel is one of the most widely available software tools available, to analyse the most diverse types of data. This software could create charts and graphs, also have a library with a huge amount of commands, for example AND, OR, SUM, etc.

Excel will be very useful to organize the data in matrices for a post analyse by Matlab.

#### **2.4.1.2 Matlab**

Matlab is used by millions of scientists and engineers, in order to analyse and design the systems around the world. The Matlab matrix-based platform is optimized for solving a wide variety of engineering problem, and also the most natural way to express computational mathematics. The built-in charts are made in order to easily visualise and gain insights data.

All this, combined with an extended library, make matlab the perfect device for the project objectives. Therefore matlab's mission in the project is to facilitate data analysis, saving a lot of time.

On chapter 3, the methodology and all the work done by the student will be discussed.

### 3 Methodology

The methodology has the mission of show the work done during the project.

#### 3.1 CoP

First it is necessary to establish a rule to calculate the CoP.

The CoP can only be calculated when the system is working, and to know if the system was working the following topics were used:

1 – If the power consumed by the system is lower than the average power, we concluded that the system is not working and the ASHP is on standby configuration;

2 - If the DeltaT is lower than zero, so CoP is equal to zero, because if the water that is returning for the tank is higher than the water pumped from the pump to the tank, so the house is already warm, and the house is heating the water and not the ASHP. So, the ASHP is on standby configuration.

Knowing the above rules, the project can precisely analyse the system.

### 3.2 Field Approach

The first thing that have to be done to begin the project is the field approach, which is basically go to the place with the system (ASHP), understand how the system works, take some pictures to study what are the best places to put the sensors to acquire data. The representation below (figure 3.1) is showing the system as a whole.

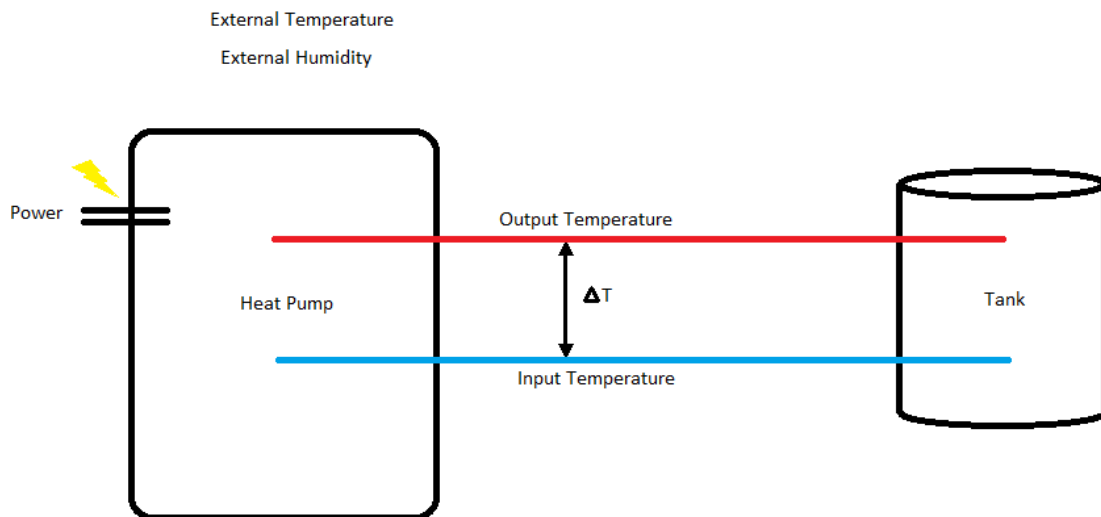


Figure 3.1 – System Units

After understand the system, it is time to survey regards data loggers, and what is the best way to install the components.



### 3.3 Data Loggers Survey

The survey about the data loggers could be seen on Chapter 2 (2.2 Type of Data Loggers).

However the following topics will show all the work done on the low cost board before the abandonment of the idea, for example the design, the transmission of data, etc.

#### 3.3.1.1 Conversion of electrical

If the sensor returns a value of voltage between 0 -5 V, the processor will convert (ADC) and read a value between 0 – 1023 (10 bits).

If the sensor returns current, we will put a resistor to read voltage. Then the processor will convert (ADC) and read a value between 0 – 1023 (10 bits).

Then the processor will store the data in the SD card, using a temperature variable.

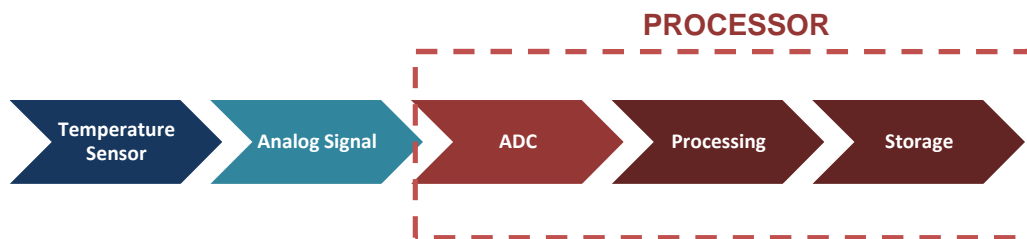


Figure 3.2 – Illustration of the conversion of electrical signals from sensors to environmental data values

#### 3.3.1.2 Logging of data values

All data will be storage at the SD Card by communication SPI Bus.

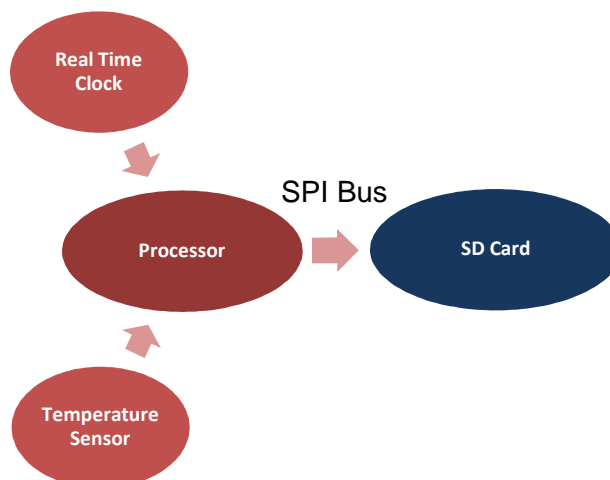


Figure 3.3 – Illustration of the communications

The storage will use the FIFO format, showed in the diagram below.

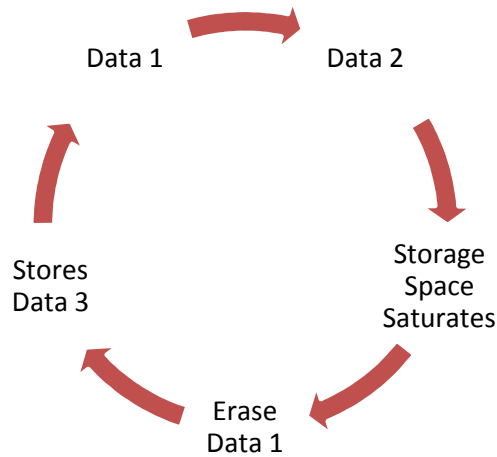


Figure 3.4 – FIFO format

### 3.3.1.3 Transmission of data

The type of communication that is going to be used on the project is the SPI protocol. This protocol uses one wire to establish the clock of the system (SCK) and it is done exclusively by the processor (master), one wire to send the data from the master to the slave (MOSI), another one in the opposite direction (MISO) and an additional wire for each sensor used (SS). The method of the protocol is illustrated as following and its characteristics as well.

Advantages of SPI	Disadvantages of SPI
- Faster than asynchronous serial	- It requires more signal lines than other
- The receive hardware can be a simple shift register	- The communications must be well-defined in advance
- It supports multiple slaves	- The master must control all communications;
-	- It usually requires separate SS lines to each slave, which can be problematic if numerous slaves are needed.

Table 2 – Advantages and disadvantages of SPI

### 3.3.1.4 Configuration of system to turn logging on and off

We will be able to choose when the system will begin to acquire data, for how long will acquire data, the sample time and the time that the system will stop. All these features will be guaranteed by programming the processor (C++).

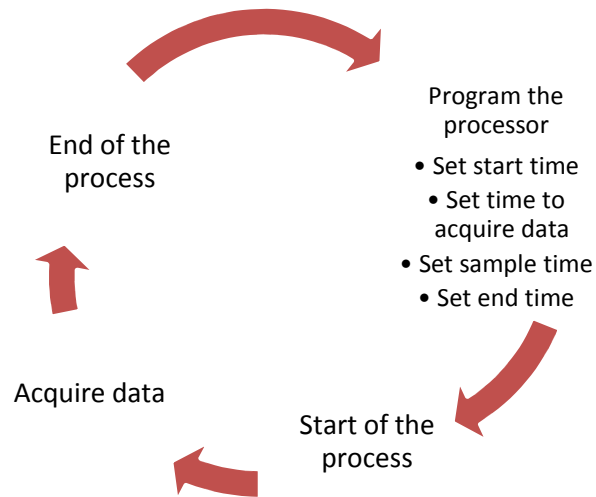


Figure 3.5 – System settings

### 3.3.1.5 Analysis of Data

The SD Card will provide a text file and using Matlab software it will be possible to read that file, analyses it through the techniques that is going to be developed, displays all the data on charts and makes comparisons with other data acquisitions.

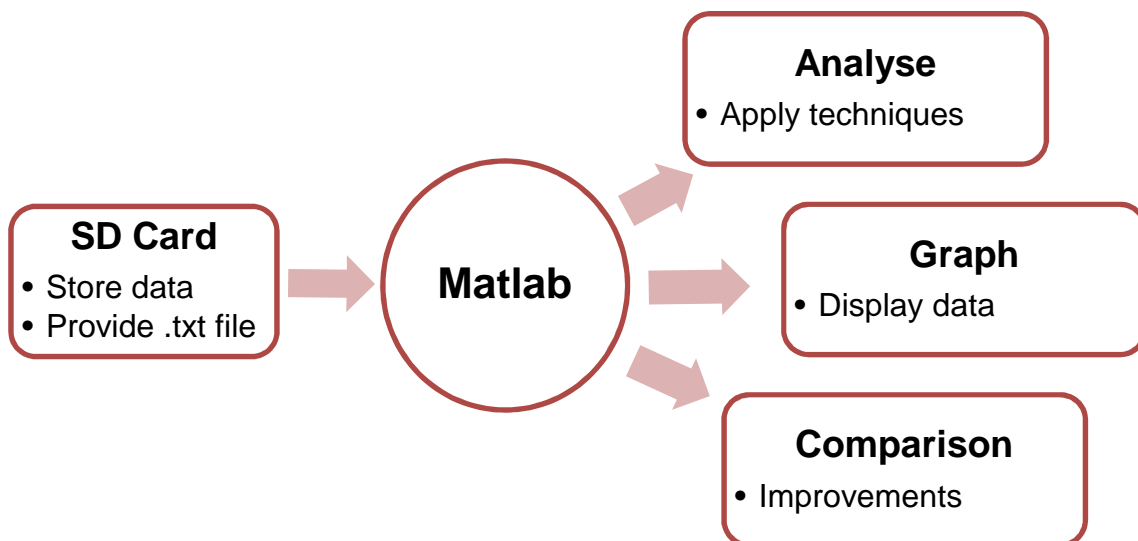


Figure 3.6 – Data analysis diagram

### 3.3.1.6 Board Design

After deciding all the board components, the design of the board need to be done, and the software called Proteus, will be the software used to design the board. Below there are two figures showing in the first one all the connections between the pins, and the second figure the real design of the board, the final design, or in other words, how the board will look like at the end of the production.

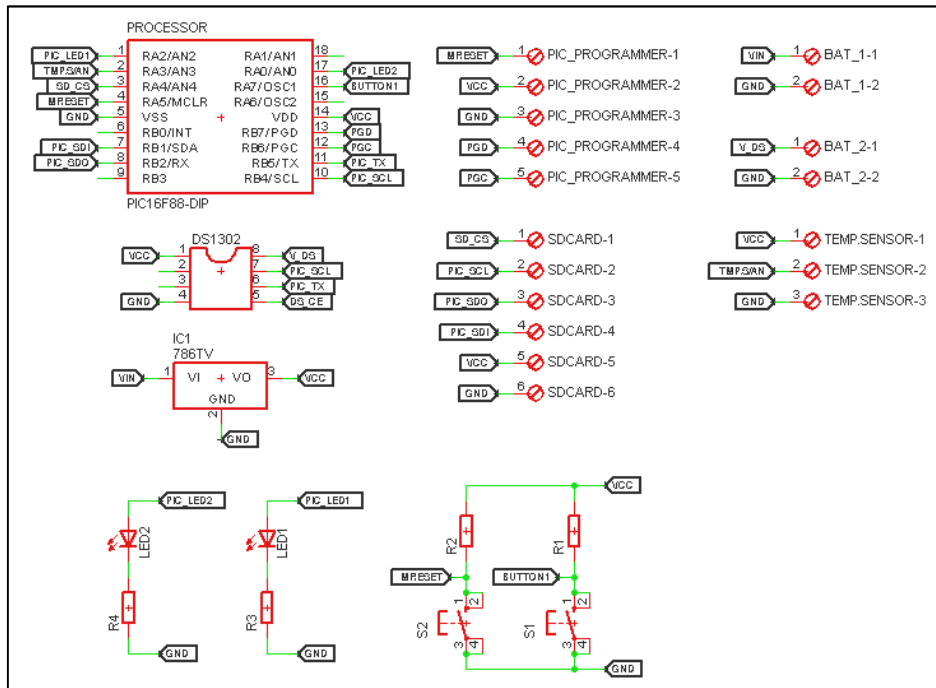


Figure 3.7- Board representation

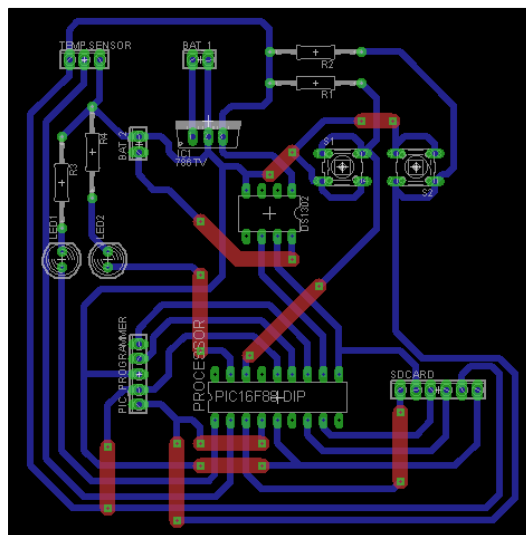


Figure 3.8 – Board design

### 3.4 Choosing the data loggers

Then, all the four data loggers are compared on the table below.

<b>Data Logger</b>	<b>Advantages</b>	<b>Disadvantages</b>
<b>EL-USB-2</b>	<ul style="list-style-type: none"> <li>• Temperature sensor</li> <li>• Humidity sensor</li> <li>• Linked Battery</li> <li>• USB connection</li> <li>• Easy set up</li> </ul>	<ul style="list-style-type: none"> <li>• Do not have power meter</li> <li>• Do not fit in all places</li> </ul>
<b>iButton</b>	<ul style="list-style-type: none"> <li>• Temperature sensor</li> <li>• Linked Battery</li> <li>• Fit in all places</li> <li>• Easy set up</li> </ul>	<ul style="list-style-type: none"> <li>• Do not have power meter</li> <li>• Do not have humidity sensor</li> <li>• Need an adapter</li> </ul>
<b>Low Cost Board</b>	<ul style="list-style-type: none"> <li>• Temperature sensor</li> <li>• Humidity sensor</li> <li>• Power meter</li> <li>• USB connection</li> <li>• Low cost</li> </ul>	<ul style="list-style-type: none"> <li>• Short Deadline</li> <li>• Difficult to built</li> <li>• Constant power supply</li> <li>• Difficult set up</li> </ul>
<b>Emon System</b>	<ul style="list-style-type: none"> <li>• Temperature sensor</li> <li>• Humidity sensor</li> <li>• Power meter</li> <li>• Fit in all places</li> <li>• USB and Wi-Fi connection</li> <li>• Easy set up</li> </ul>	<ul style="list-style-type: none"> <li>• High cost</li> <li>• Constant power supply</li> </ul>

**Table 3 – Systems advantages and disadvantages**

After summarising the differences between the systems, the system that will be used to capture the input and output temperature and also the energy spend on ASHP is the Emon System, which is the most capable system, that will attend to all the project major demands. The EL-USB-2 will be placed in a strategic location to acquire the external temperature.

In a whole, the system is composed by an emonPi, an emonTx and one EL-USB-2.

### 3.5 Data Loggers Location

After deciding what are the data loggers which will integrate the project, the location of each one must be decided. So, the following figure (figure 3.9) is showing how the data loggers will be placed on the whole system, to acquire more precisely the system data.

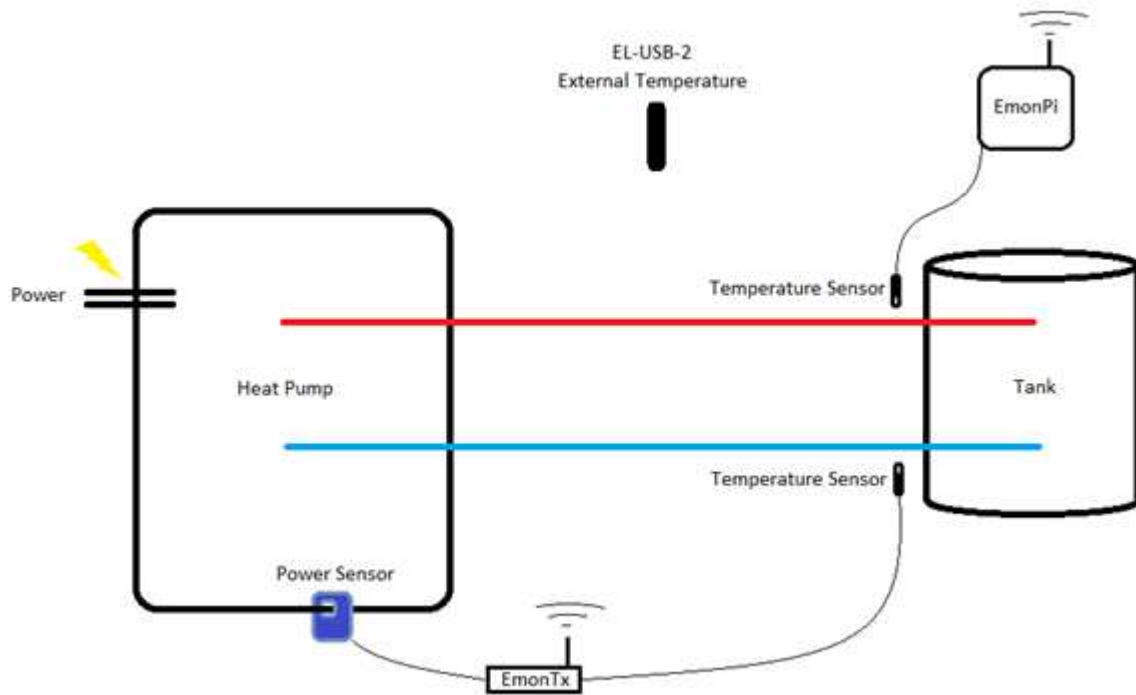


Figure 3.9 – Sensors locations

After deciding the best places to install the components (data loggers), the next step is realize the field test or in another words, the practical test (the tests will be showed on Chapter 4 Evaluation).

### 3.6 Matlab Programming

The most important part of the project is the Matlab programming. The programming is where all the data will be analysed for the understanding of the information acquired by the data loggers.

#### 3.6.1 Data organization

First of all, it is necessary to combine the data acquired by the emonPi with the data acquired by the emonTx, because in some cases emonTx could lose some values, in reason of the communication between emonPi and emonTx is via radio. So, the first part of the programming was made to organize all the data correctly. Below you can see the programming with the commentaries (%% ...commentary ...).

```

clc;
close all;
clear all;

k=1;
i=1;
j=1;
cab = 0; %% number of lines to ignore

fid = fopen('file.txt'); %% open file

for i=1:1:cab
    t = fgetl(fid); %% read the data from the file
end

Data = textscan(fid, '%f%f%f%f%f'); %% store 5 variables in the matrix Data
fclose(fid);

linesi = length(Data{3}); %% gets the size of the matrix Data{3}
linesj = 27553

for i = 1:linesi
    for j = k:linesj
        if Data{3}(i,1) == Data{5}(j,1) %% compare the values
            Cdata{1}(k,1) = Data{1}(i,1); %% organize the values
            Cdata{2}(k,1) = Data{2}(i,1);
            Cdata{3}(k,1) = Data{4}(j,1);
            k = k+1
        else
            j = j+1;
        end
    end
    i = i+1
end

```

### 3.6.2 Calculation of CoP and DeltaT

In the second part, the program will read all data organized in step 1 (3.5.1), and with the data the CoP and the DeltaT will be calculated. Below is showed the step 2 of the programming. Below is showed the second step of the programming with commentaries.

```
lines_cop = length(Data{1}); %% gets the size of the matrix Data{1}

PowerM = mean(Data{1}) %% calculate the average power

for i = 1:lines_cop
    Data{4}(i,1) = Data{3}(i,1) - Data{2}(i,1); %% calculates DeltaT
    Data{5}(i,1) = ((Data{4}(i,1))*1.25*3.782)/(Data{1}(i,1)/1000); %% COP

    if Data{5}(i,1) <= 0 | Data{1}(i,1) <= PowerM | Data{4}(i,1) <= 0
        Data{5}(i,1) = 0;
    end
    i = i+1;
end

for i = 1:lines_cop
    if Data{5}(i,1) ~= 0
        Mat(j,1) = Data{5}(i,1);
        j = j+1;
    end
end

Cop_Real_Ave = mean(Mat) %% calculate the average CoP
```



### 3.6.3 Plotting

In the last part of the program, Matlab will acquire all information stored by step 2 (3.5.2), and will plot the vital information for later analyse by the programmer. Following is showed the final part of the programming with the commentaries.

```
for i =1:lines_cop
    Data{6}(i,1) = (Data{1}(i,1))/1000 ; % transform W into kW
end

figure(1)
subplot(1,1,1);plot(1:1:lines_cop,Data{2},'r',1:lines_cop,Data{3},'b',
1:lines_cop,Data{4},'g'); % plot figure(1)
xlabel('Samples');
ylabel('Values');
legend('Tout','Tin','DeltaT','Location','NorthEastOutside');
hold on;

figure(2)
subplot(1,1,1);plot(1:1:lines_cop,Data{5},'m',1:lines_cop,Data{6},'y',
1:lines_cop,Data{4},'g'); % plot figure(2)
xlabel('Samples');
ylabel('Values');
legend('CoP','Power','DeltaT','Location','NorthEastOutside');
```

On the next chapter 4, will be discussed how the tests will be realized and how it is going to happen.

## 4 Evaluation

In this section of the project, all the tests done in the project will be highlighted to provide a greater understanding of the work carried out.

### 4.1 EL-USB-2

#### 4.1.1 Home Test

To understand how the EL-USB-2 works, a home test was made. First the EL-USB-2 was set using the data logger software, to acquire data (temperature and humidity) every thirty seconds. Then the data logger was placed next to the heater to acquire the temperature variation during a day, and with this test, were learned how is the best way to configure and place the component on field.

#### 4.1.2 Field Test

The EL-USB-2 was placed outside to acquire the external temperature. Below, the figure shown how the data logger was placed to acquire the temperature



Figure 4.1 – External temperature

## 4.2 Emon System

### 4.2.1 Home Test

Just like the EL-USB-2, some home tests were made with the intention of learning the best way to configure and place the Emon System components (EmonPi and EmonTx).

It was noted during the tests a software problem on Emon System. The system was not recognizing the connected sensors and with this, the system was not acquiring the data.

The problem solution was to send an email to the manufactures asking for answers. So, the manufactures answered, asking to change some configuration on the system to see if there are any responses from the sensors.

After changing the recommended configurations on the Emon System, just a temperature sensor seemed to be working (and sometimes, even this sensor did not work).

So, the sensors were tested via a multimeter, and it was noticed that the sensors were also sharing problems. The manufactures were contacted, and the project received a new pair of temperature sensors, now working perfectly.

If the tests were not performed, maybe these problems mentioned before, would only be discovered in the main phase of the tests.

Below is showed the diagram (figure 4.2) with the location of the sensors in the home test.

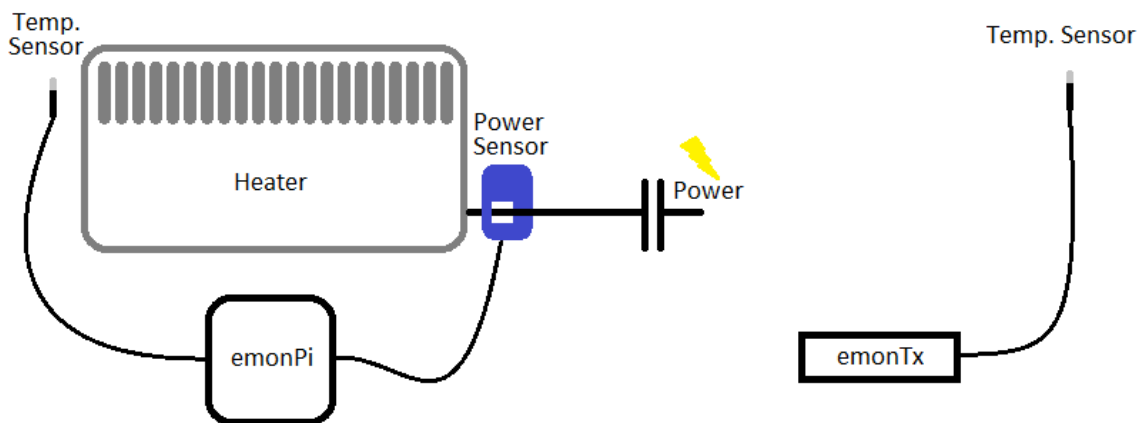


Figure 4.2 – Home test sensors locations

#### 4.2.2 Field Test

The field test was realized putting the emonPi temperature sensor to measure the water coming from the house colder without the heat (Return Temperature). EmonPi also measure the power spent by the heat pump. On the other hand, the emonTx temperature was located on the inlet pipe, in other words the water heated coming from the heat pump (Inlet Temperature).

Apart the figure 3.9 (Chapter 3), the following images were taken in the last visit to the house which the ASHP is installed, and they give to the reader a better perspective of the tests.



**Figure 4.3 - Evaporator**

The above figure (figure 4.3) shows the evaporator part of the Air Source Heat Pump, placed outside of the house in the garden.

The both sides of the figure (figure 4.4) below shows the emon system placed to acquire the respective temperature and power where,

The yellow square shows emonTx component;

The blue square shows emonPi component;

The orange circle shows the emonPi temperature sensor, placed to acquire the data coming from the return pipe;

The red circle shows the emonTx temperature sensor, placed to acquire the data coming from the inlet pipe;

The figure cuts the power sensor, so the yellow arrow shows that the power sensor is placed more to the left to acquire the power spent by the pump.

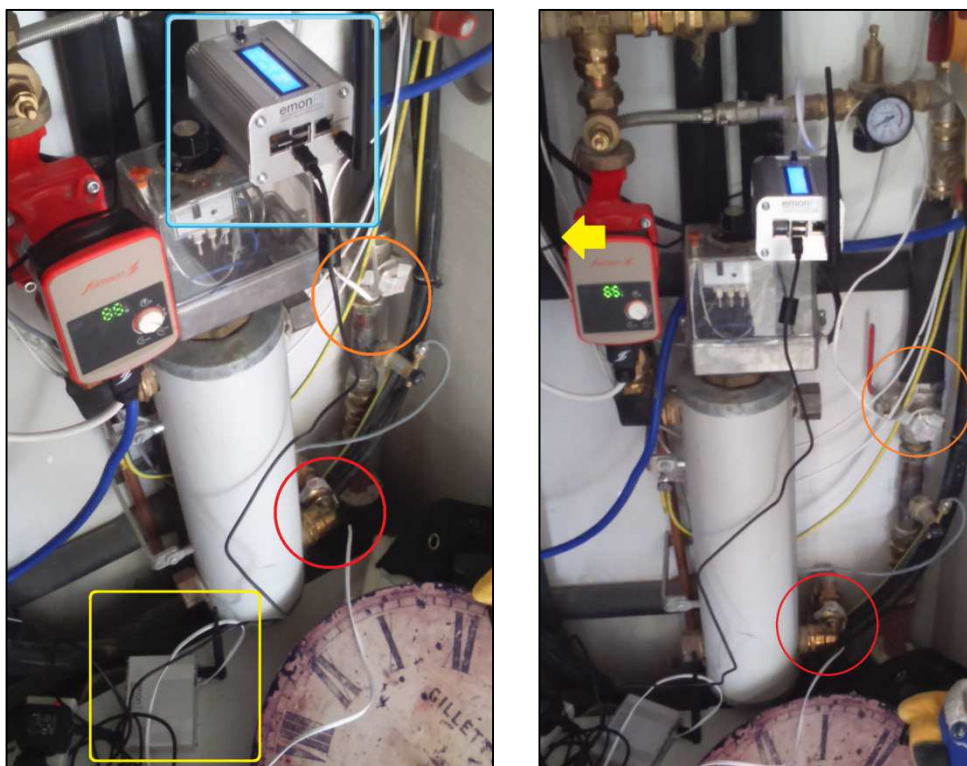


Figure 4.4 – Emon system location

## 4.3 Matlab

### 4.3.1 Test using pre-determined values

This test is important to make sure that the designed programming is working. For this reason it used pre-determined values which the programmer knows the results of the equations. Then, after running matlab programming, the programmer can compare the results and be sure that everything is ok. Below (figure 4.5) it is showed the initial matlab display where all the programming will be done.

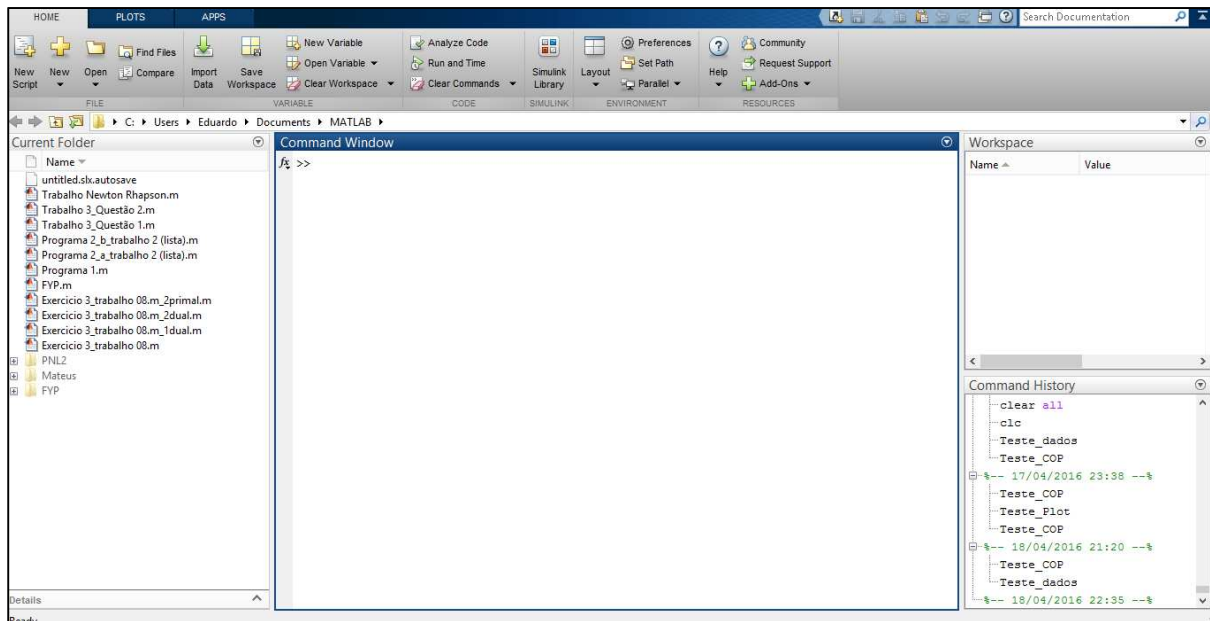


Figure 4.5 – Matlab initial display

### 4.3.2 Test using real values

After making sure that the entire program is working, the real data acquired by the emon system were downloaded to matlab, and the real test was performed.

The next chapter 5, will highlight the results of the above tests.

## 5 Results

In this chapter, all the results of the previous test will be described.

### 5.1 Emon System with EL-USB-2 results

Timestamp data was synchronised between the emonPi and emonTx readings. The acquired data from emon system occurred as expected with emonTx losing some values, due the radio communication between both components.

So, emonPi was acquired 59480 samples of power and return temperature, and emonTx was acquired 22500 inlet temperature. Finally the EL-USB-2 provided 1135 samples because the acquiring time for each sample was different than emon system.

All these data will be implemented on matlab which will organize the information for a subsequent analysis.

Remembering, all the data was acquired during the spring, between 18<sup>th</sup> of March 2016 to 13<sup>th</sup> of April 2016.

### 5.2 Matlab Results

#### 5.2.1 Pre-determined values

The first figure below (figure 5.1) shows Matlab organizing only the equal data times, and storing the information on a matrix called Cdata.

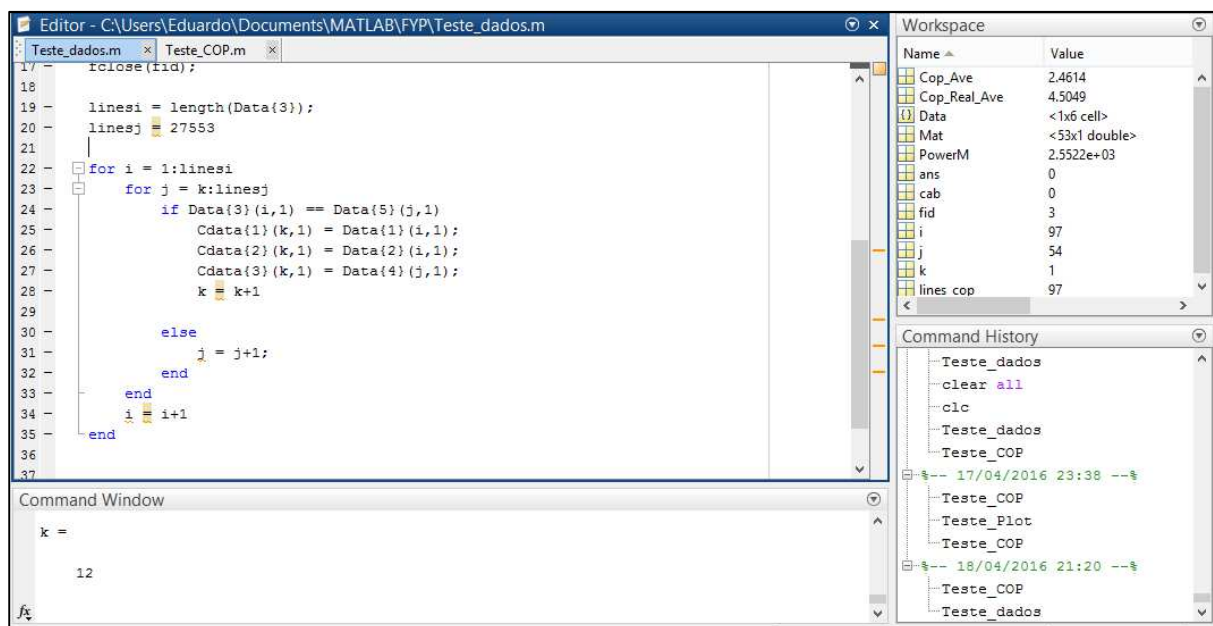
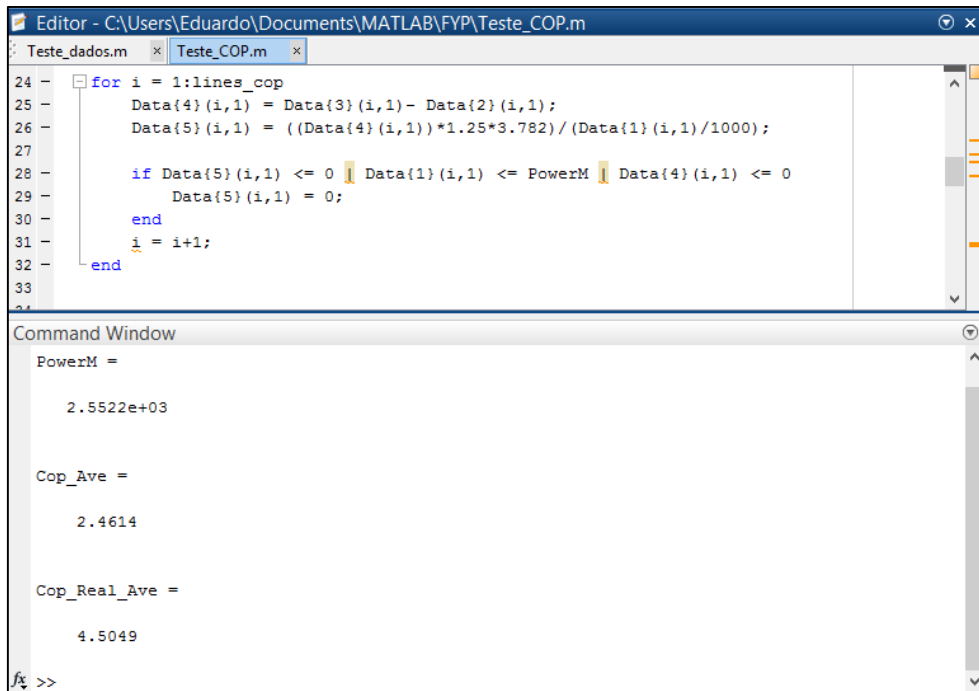


Figure 5.1 – Matlab organizing data

The figure below (figure 5.2) shows Matlab calculating the average CoP using the organized data.



```
Editor - C:\Users\Eduardo\Documents\MATLAB\FYP\Teste_COP.m
Teste_dados.m x Teste_COP.m x
24 - for i = 1:lines_cop
25 -     Data{4}(i,1) = Data{3}(i,1) - Data{2}(i,1);
26 -     Data{5}(i,1) = ((Data{4}(i,1))*1.25*3.782)/(Data{1}(i,1)/1000);
27 -
28 -     if Data{5}(i,1) <= 0 || Data{1}(i,1) <= PowerM || Data{4}(i,1) <= 0
29 -         Data{5}(i,1) = 0;
30 -     end
31 -     i = i+1;
32 - end
33
Command Window
PowerM =
    2.5522e+03
Cop_Ave =
    2.4614
Cop_Real_Ave =
    4.5049
fx >>
```

Figure 5.2 – Matlab calculating CoP

The last figure (figure 5.3) shows Matlab plotting the resulting values of CoP, DeltaT and Power.

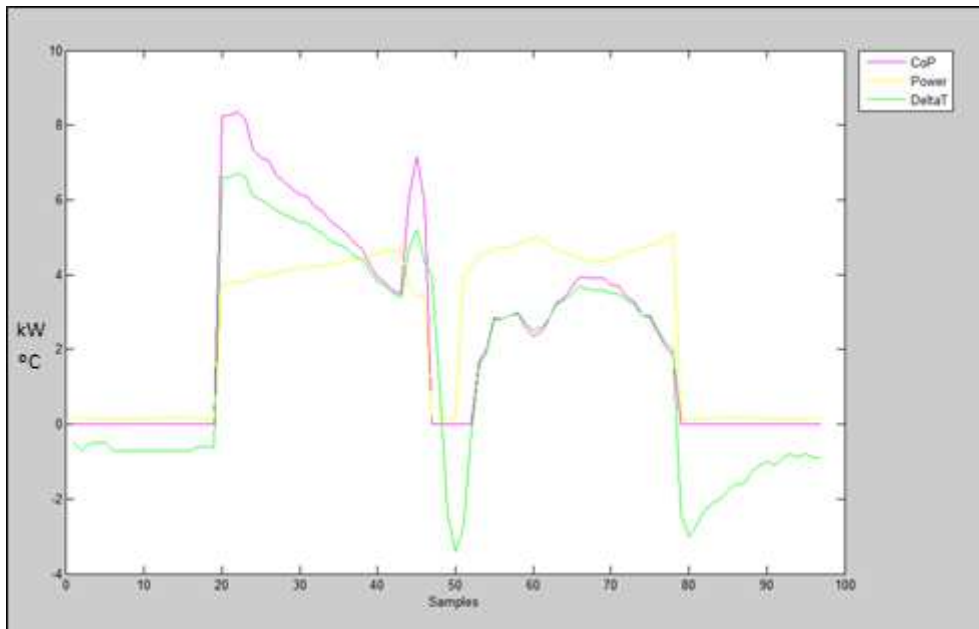


Figure 5.3 – Matlab plotting graph

Analysing the results of the above tests, it was verified that the program was working properly.



### 5.2.2 Real values

Using the first part of the program, matlab organize the 59480 samples into 22500 valid samples combining the data from emonPi with the data acquired by emonTx.

Then matlab took all the 22500 valid samples, and performed all the necessary calculations, like DeltaT, CoP, etc. Storing all the results in a matrix and showing the Average CoP and the Medium Power to user.

Average Power = 676.5252 W

Average CoP = 4.4808

Finally matlab uses the values stored in the matrix to generate the graphs showed below (figure 5.4, 5.5, 5.6 and 5.7), where all the information for a better analysis is provided.

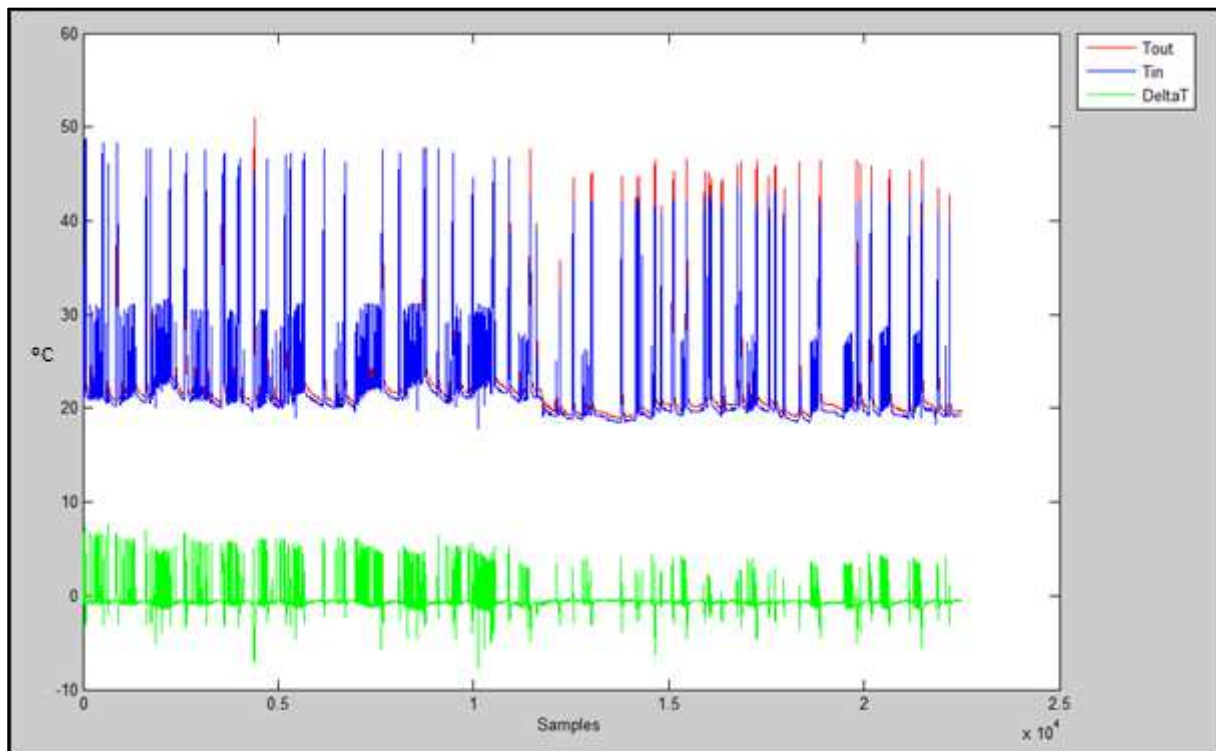


Figure 5.4 – Tout (Inlet), Tin (Return) and DeltaT Graph

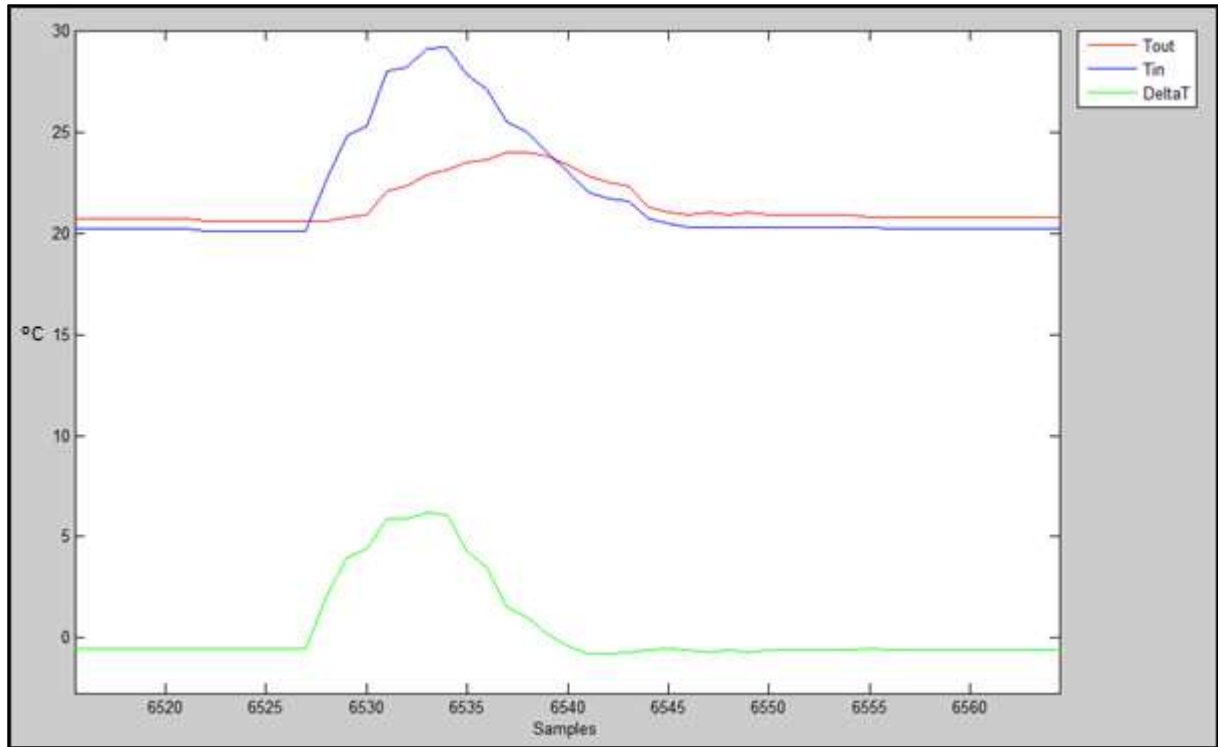


Figure 5.5 - Tout (Inlet), Tin (Return) and DeltaT Graph with zoom in

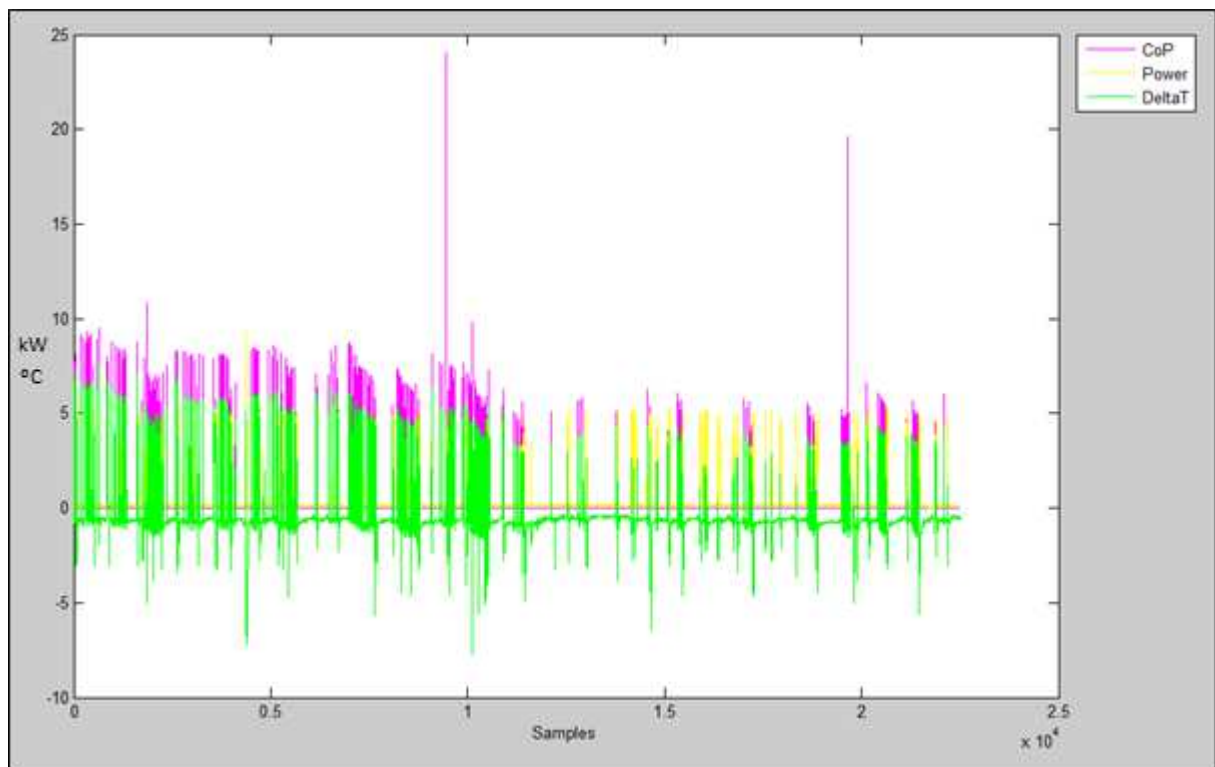


Figure 5.6 - CoP, Power and DeltaT Graph

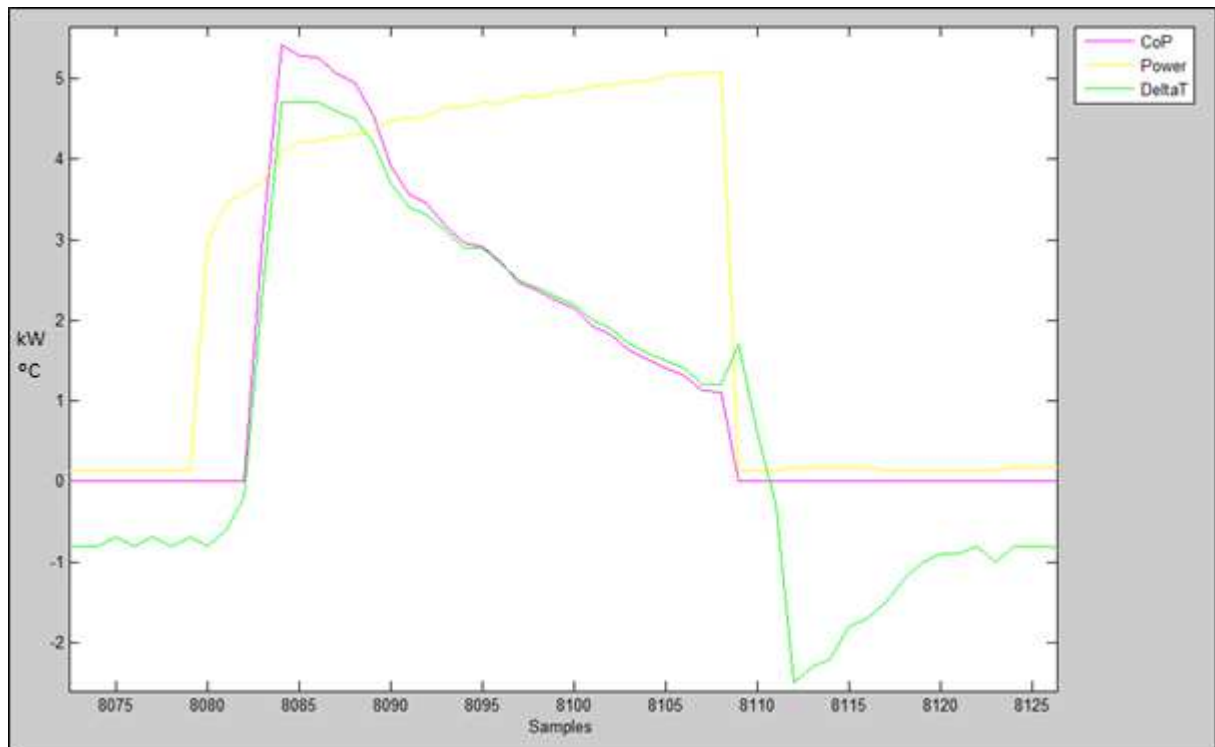


Figure 5.7 - CoP, Power and DeltaT Graph with zoom in

Finally, the project results it will be discussed on the next chapter 6.

## 6 Discussion

After all the tests and the related results, it is noted that the chosen data loggers were the correct ones for the project. The components behaviour was satisfactory, even with emonTx losing some data values during the system operation.

Taking the CoP result, and comparing it with the usual CoP given by the manufactures which built the Air Source Heat Pump, it is evident that the CoP is high, taking into consideration the time of the year which the data it was acquired.

A CoP equals to 4.48, which is a normal CoP when the summer is the season analysed, so this value of CoP is a very good value for the spring.

When we look at the CoP (figure 5.6), it is noticed that in the middle of the graph the CoP decreases, this behaviour is normal because on that time of the analysed month, the EL-USB-2 revealed that the average external temperature also decreases to about 6.25 degrees C. The first figure below, shows the zoom on the CoP, Power and DeltaT of the coldest period of the month (figure 6.1), and the second one the external temperature at the same time of the month (figure 6.2).

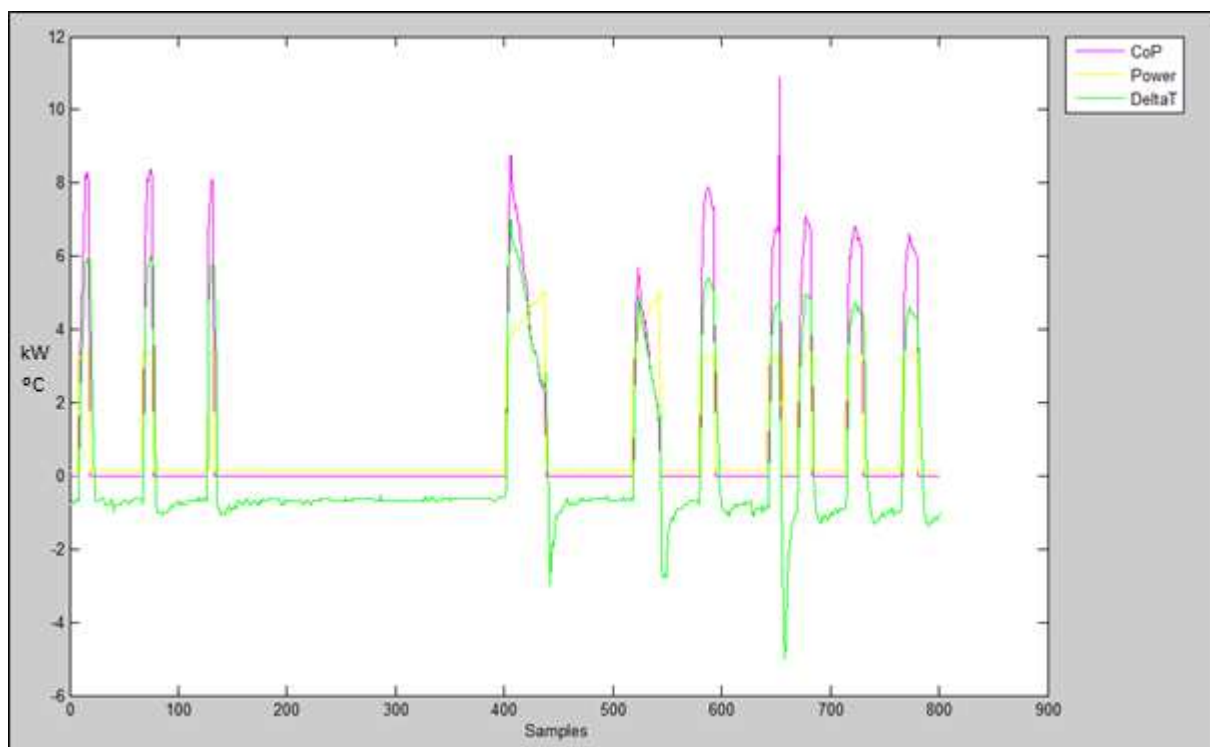


Figure 6.1 – Coldest days CoP, Power and DeltaT

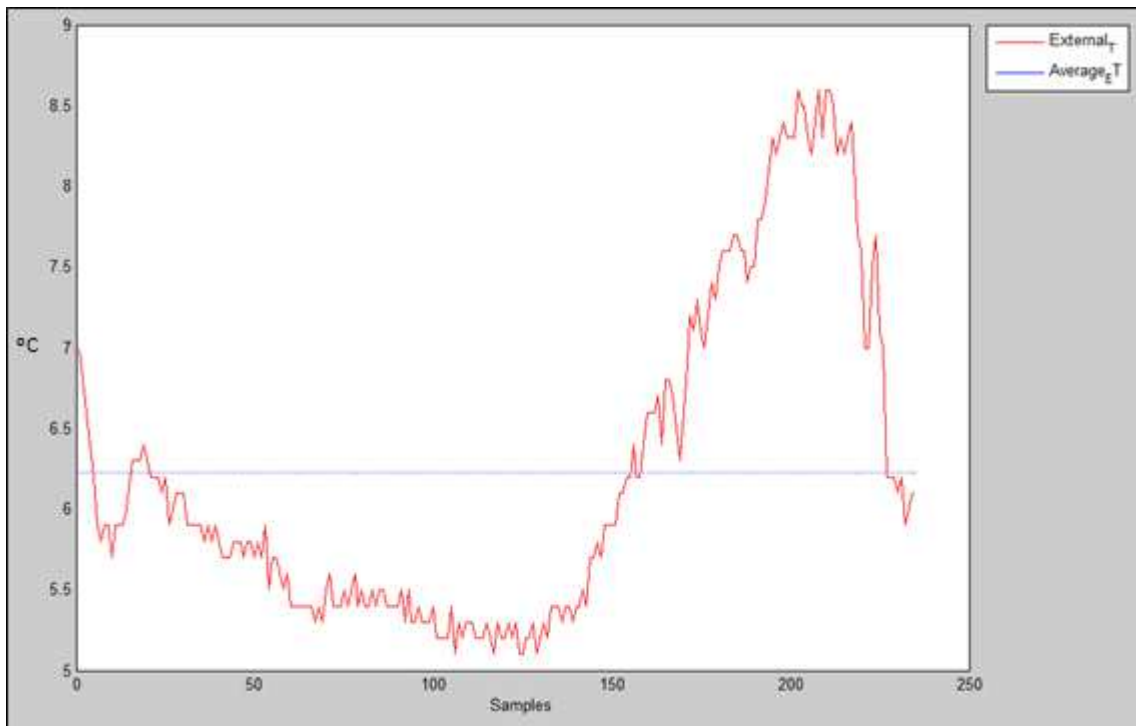


Figure 6.2 – External T coldest days

Comparing the CoP and the external temperature using a graph (figure 6.3), it is noticed that the CoP rises when the external temperature increases, proving that the CoP must be higher when the temperature is high (Summer).

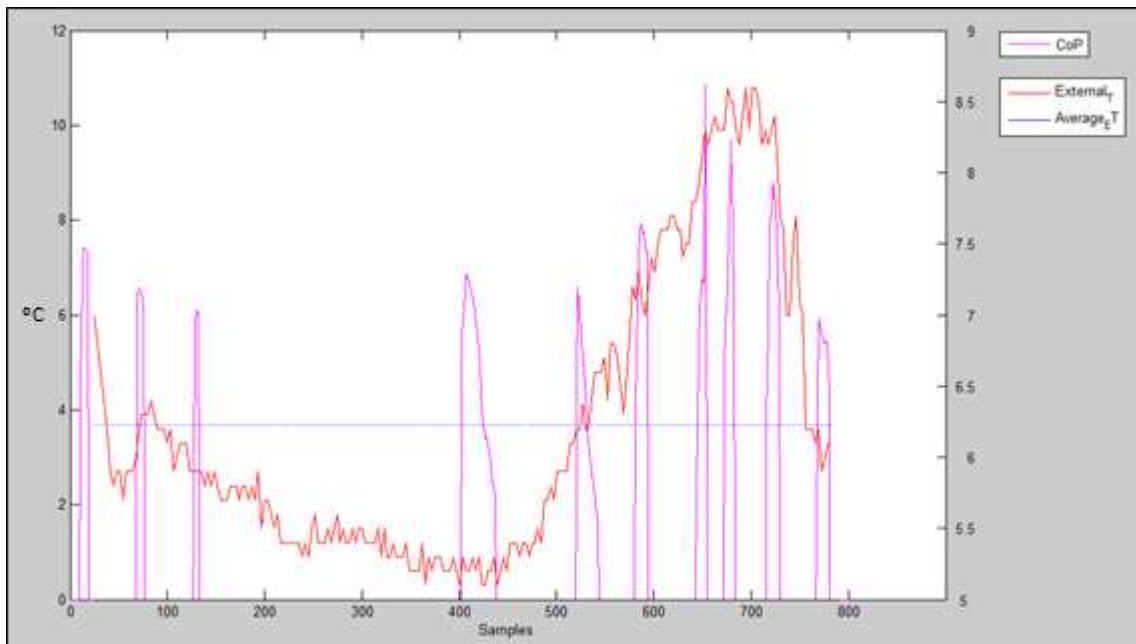


Figure 6.3 – CoP x External Temperature

Even, with these low temperatures the ASHP obtained a very good performance proving to be a very good system for a house. Also, the average power spent during the tests it was a low value compared with the others heating processes.

Another point that could be seen on the matlab graph (figure 5.7), is when the power rises to big values, the CoP falls to very low values. Therefore they are proportionally contrary to each other. On the other hand, the CoP is proportional to  $\Delta T$ .

Other good fact to discuss is while the water is being heated up, the difference of temperature decreases because the heated water begins to circulate in the system heating up the house.

Talking now, about the techniques for data acquisition, is good to see that all the previously information about the subject it was well used to acquire the necessary data.

Matlab fulfilled its purpose of facilitate the generation of graphs, tables, matrixes, and also the data analyses became much easier to do, than the normally methods.

The following chapter 7 will conclude the project.

## 7 Conclusions

Finally after discuss all the results obtained by the sensors, data loggers, and systems utilized in the project it is noticed that the ASHP in utilization, really worth the money spent on it. The studies showed that the energy consumption is lower compared to others components which are being sold on the stores, the water heating is fast, the coefficient of performance it was higher them the normal ones.

Also, an ASHP contribute to a cleaner energy, because just a small part of the system needs energy to work making the system a renewable source of energy which will help not just you, but the entire environment.

Looking now to the components which surrounds the project, most specifically data loggers and also the data analysis techniques, it is clearly that this is a great area to be explored, because the utilization of these methods are so much bigger than a home ASHP. These methods and techniques can be utilized on industries to discuss which is, the best way to save money and increase production profit. Concluding, monitoring systems it is a vast area, with a lot of paths to follow, with some of them leading to the biggest companies in the world, and with the nowadays idea of reduce the energy usage, the monitoring systems it is a great area for a modern engineer establish itself.

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