Development of an Automated Energy Management System for work spaces

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Abstract

The objective of this project is to design, develop and implement an automated energy management system for work spaces. An Energy Management System integrates air-conditioning equipment into the same platform so that they can be remotely accessed. With this system, it's easier to maintain and supervise all the equipment, simplifying the management of the building. In this experiment, only one split unit in a small work space will be integrated. To fulfil that, an Arduino Uno will be used to remotely command the environment unit, removing the traditional infrared remote device. Using this system, positive results will come in thermal comfort, using the PMV-PPD (Predicted Mean Vote – Predicted Percentage Dissatisfied) Model, by Fanger. Also, by updating an old air-conditioning unit, better energy results will come, improving the energy efficiency.

Since Arduino it's a low budget tool, it's expected to get the same results as more expensive integrated systems. Big companies, like EDP, Siemens, Schneider and so on, have large Building Automation Systems that come with big costs. In this project, the objective is also to lower that feed and provide a simple and functional system, that can fulfil all the requirements.

Keywords: Energy Management, Arduino, HVAC, PMV-PPD, Comfort

1 Introduction

We live in a time where technology represents an important role in our lifestyle. Using those tools, it's possible to improve energy management systems without losing comfort., therefore improving energy efficiency. With that information and looking at HVAC systems, there is a big opportunity to improve and understand better the area.

Arduino is a very powerful and low budget tool that helps people with low programming skills to improve their programming. Since is open-source, easy to implement and has a very large community, it's very easy to find information and to ask for about, regarding a lot of different topics.

This project focuses in individual climatization systems (split units), which are designed with 1 equipment that insufflates air for a specific building zone. So the case study is for small divisions with one individual split unit, controlled by infrared remote equipment.

1.1 Bulding Automation Systems (BAS)

Smart Buildings give services that helps users to become more productive, with less environment impact and with low costs associated This Buildings use technology to integrate the very subsystems that work in a independent way. Even independent they can trade information between them and the users to help improve the total efficiency system. Building Automation System (BAS) is responsible for managing and measuring the Buildings activities, such as:

- Heating, Ventilation and Air Conditioning (HVAC);
- Lighting
- Security
- Fire

There are a lot of benefits in using an BAS:

1. Energy savings;
2. Environment impact;
3. Security improve;
4. Building Maintenance;
5. Logistics (see the building status without being present);

1.1.1 Arduino

The Arduino was born in northern Italy to help students without programming and electronics knowledge. The project is open-source, based on simple use hardware and software.

The Arduino board (Figure 1) can read Inputs and write outputs using instructions, written in a built microprocessor. The programming language is based on Wiring, which is smilar to C/C++ and the software based on Processing, which is called IDE.

Figure 1 - Arduino Board

There are a lot of benefits in using an Arduino, which one:

1. It’s possible to run in MAC, Windows or Linux OS;
2. Easy to use;
3. Auxiliary components at low costs;
4. Open-Source;
5. Large community with a lot of examples;
6. The Price;

Using the Arduino is possible to control a split unit to climate a small space, by using an infrared LED. The aim is to replace the remote controller and control all actions with the Arduino CPU.

2 Building Climatization

2.1 Thermal Comfort

“*Thermal Comfort is that condition of mind that expresses satisfaction with the thermal environment”* (ASHRAE Standard 55)

This definition explains what thermal comfort means. It is very complicated to resume thermal comfort in one stance, because to reach that state a lot of parameters are necessary. Body temperature, low skin moisture and minimal physical effort are some of the parameters necessary to get in comfort.

2.1.1 Energy Balance

The equation (1) describes the interaction between the human body and the surrounding environment.

$$M - W = q_{sk} + q_{res} + S \qquad (1)$$

Where $M - W$ is the difference between the metabolic fluxes and the mechanical work, q_{sk} the heat flux from skin, q_{res} the heat flux from respiration and S the stored heat flux in W/m^2. To simplify the calculation, we assume the mechanical work to be zero, since it’s very low comparing to the metabolic.

2.1.2 Metabolic Work

The unit to describe the metabolic work is known to be met, which 1 met corresponds to 52,1 W/m^2. This value depends a lot in the activity level of the person. A person working in the office, just writing some papers produces a level of metabolic work of 60 W/m^2.

2.1.3 Clothes Isolation

The clothes are very important to reach thermal comfort, because it influences heat losses and changes the energy balance of the human body with the surrounding environment.

The value of the cloth isolation is described in clo units. 1 clo is equal to 0.115 m^2k/W. The following **Erro! A origem da referência não foi encontrada.** represent the very cases for different clo values.

2.1.4 Comfort Conditions

ASHRAE Standard 55 specified comfort zones for Winter and Summer, with an clo value between 0.5 and 0.9 and 80% of sedentary persons. In Figure 2, the comfort zones can be observed in a psychometric graph.

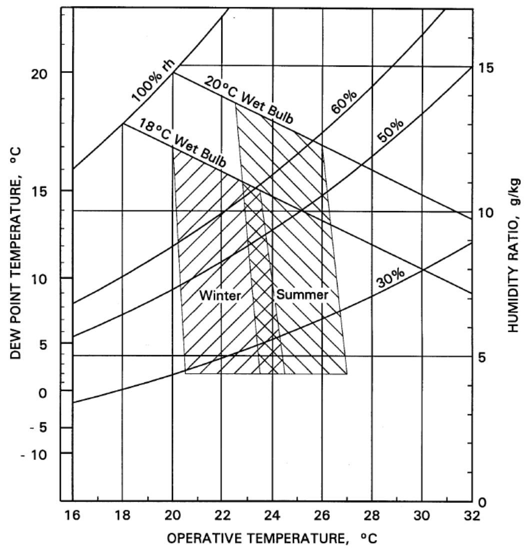


Figure 2 - Comfort Zones

2.1.5 Thermal Comfort Prediction

In this project the prediction method used was the “Predict Mean Vote (PMV) – Predicted Percent Dissatisfied PPD)”, by Fanger.

Fanger related the comfort and physiologic information to one equation known as the equation for thermal comfort. It’s the result of an energy balance between the metabolic work and the heat dissipation of a neutral feeling. The result of that is express in equation (2):

$$\begin{aligned} M - W = {} & 3.96 \times 10^{-8} f_{cl}[(T_{cl} + 273)^4 - (\bar{T}_r + 273)^4] + f_{cl}h_c(T_{cl} - T_a) \\ & + 3.05[5.73 - 0.007(M - W) - P_a] + 0.42[(M - W) - 58.15] \\ & + 0.0173M(5.87 - P_a) + 0.0014M(34 - T_a) \end{aligned} \quad (2)$$

Where P_a is the evaporated water pressure in the environment kPa, f_{cl} is the cloth area factor (non-dimensional), T_a is space temperature, T_r is the mean radiant surface temperature and M the metabolic work.

2.1.6 Predicted Mean Vote – PMV (ASHRAE)

The PMV predicts the average value of a large group of person vote based on ASHRAE thermal sensation scale. This scale is represented by:

+3	Hot
+2	Warm
+1	Slightly Warm
0	Neutral
-1	Slightly Cool
-2	Cool
-3	Cold

The PMV is given by the equation (3):

$$PMV = [0.303e^{-0.036M} + 0.028]L \quad (3)$$

Where L is the difference between the left and right members of the equation (2).

2.1.7 Predicted Percent Dissatisfied – PPD (ASHRAE)

After the PMV calculated, Fanger related the PPD with the PMV in one equation. The result is in equation **Erro! A origem da referência não foi encontrada.**:

$$PPD = 100 - 95\exp(-[0.03353PMV^4 + 0.2179PMV^2]) \quad (4)$$

The result of the PPD equation can be observed in Figure 3. It's possible to see that even if PMV is equal to zero, 5% of users will be unsatisfied, which means that is not possible to please everyone.

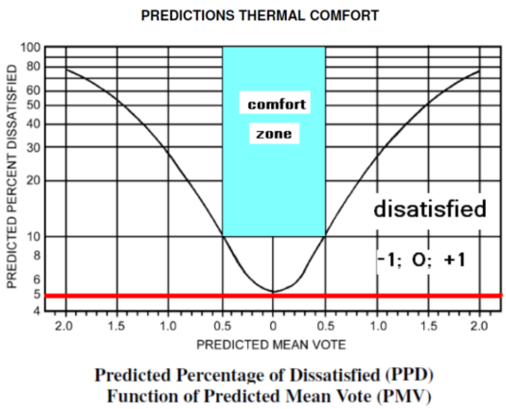


Figure 3 - Prediction of thermal comfort

3 Developed Project

The project was developed to be used in work spaces. In Figure 4 it's possible to see the space size that was used in the case study. In this space there was an split unit responsible for the environment climatization. The space was a 2m window which is directed to SW, receiving a lot of thermal energy from the Sun.

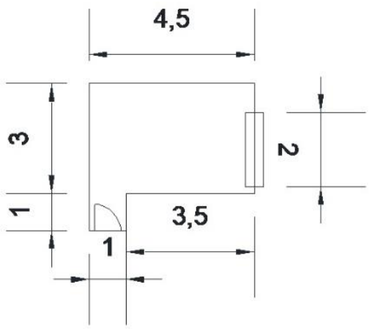


Figure 4 - Small work space study

To control the split unit, an Arduino Uno was used. With a temperature sensor (DLHT11 was used because of the price) and an infrared LED was possible to measure the room temperature and send the command outputs responsible for the unit control.

Before giving the infrared commands, it was necessary to clone the split unit remote device. Using a solution given by other people, was possible to register the code for the infrared remote device. In Table 1, it's possible to see those infrared codes that the receptor gave.

Table 1 - Infrared Codes

Pretended Command Output:	Code:
Turn on to heat	Raw: (307) 3428, 1692, 452, 396, 452, ...
Turn on to cool	Raw: (307) 3444, 1676, 456, 420, 420, ...
Turn off	Raw: (307) 3428, 1692, 428, 424, 448, ...

Since the infrared codes were very long and heavy, the Arduino SRAM failed to compile and download the programming code to control de hvac unit. The solution found was to store the infrared variables in another memory of the CPU: the flash memory. To do that, an Arduino function available: PROGMEM was used, which is a available official library from the Arduino foundation.

Even with the CPU problem solved, another one came in action. Using the PROGMEM library, the infrared code sent a different signal, with different wave lengths. To solve this situation, another extra code was used, that reproduce the same signal was before and solved the problem in hands.

3.1 Climatization Automatic Control

With the unit being controlled remotely, a switch on&off command was used, with an hysteresis. The objective of the hysteresis was to prevent the system to always send turn on orders and ten turn off orders, giving a loop of commands that was not pretended to occur. In Figure 5 it's possible to see the benefit of that function.

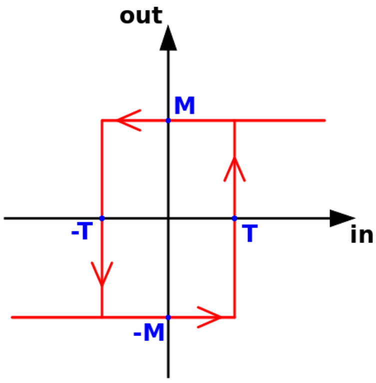


Figure 5 - Hysteresis function

With the programming code finalized and the system ready to work, there was time to register the work space temperature and to analyse those results. In Figure 6, the Arduino system is represented, where a green, blue and red LED were used to inform if the space temperature were in the comfort zone by the ASHRAE conditions.

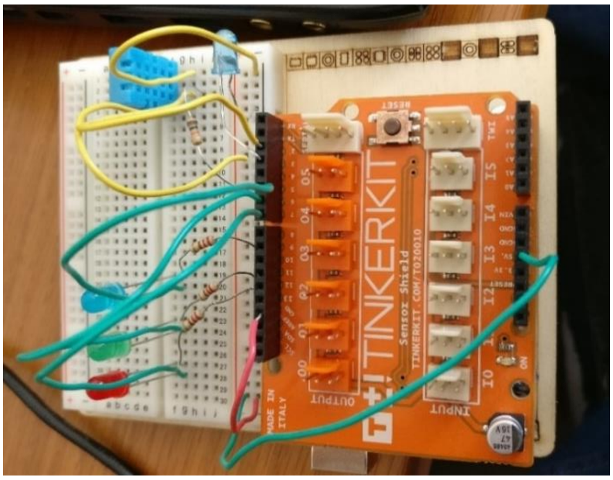
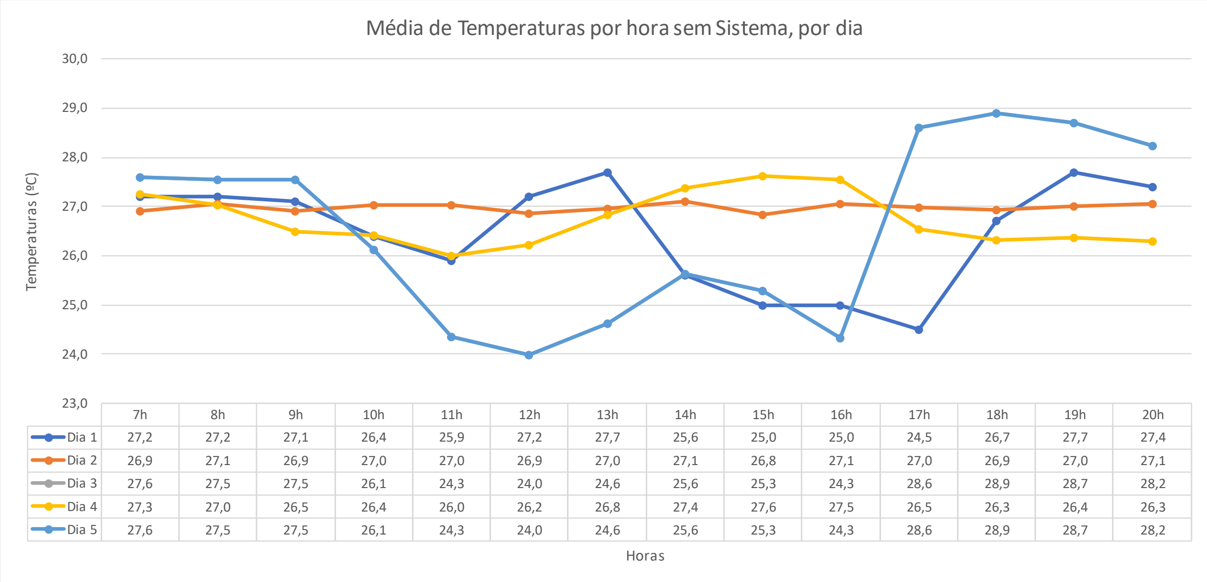


Figure 6 - Developed System

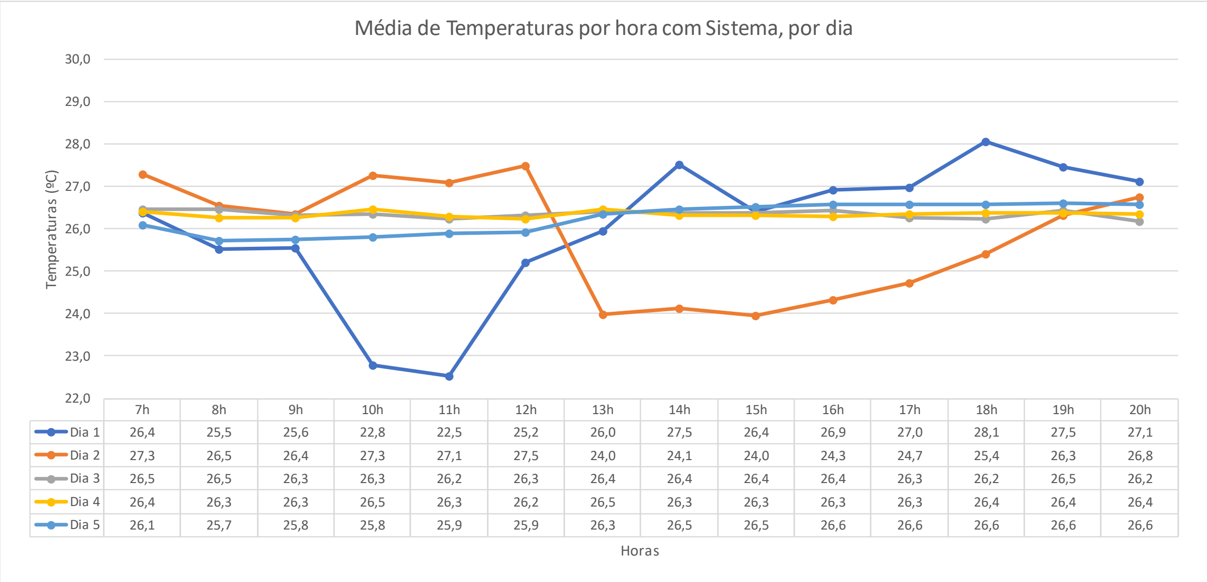
4 Experimental Results

The results were satisfied and, given the environment conditions (The study was made in very hot days of summer time), the system worked fined and without trouble. Since was a work space, there were a schedule for work hours. The system started to work at 9a.m. and stopped at 12a.m., with 1 hour of lunch break. At 2p.m. the system started to work again, until 6p.m. (the usual time to leave to work). There was a comparison of the unit working with the Arduino controller and without that controller. In Figure 7 is represented the Space Medium Temperatures without Arduino system in a hour basis. In Figure 8 is represented the same, but with the Arduino system working in a hour basis.



	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h
Dia 1	27,2	27,2	27,1	26,4	25,9	27,2	27,7	25,6	25,0	25,0	24,5	26,7	27,7	27,4
Dia 2	26,9	27,1	26,9	27,0	27,0	26,9	27,0	27,1	26,8	27,1	27,0	26,9	27,0	27,1
Dia 3	27,6	27,5	27,5	26,1	24,3	24,0	24,6	25,6	25,3	24,3	28,6	28,9	28,7	28,2
Dia 4	27,3	27,0	26,5	26,4	26,0	26,2	26,8	27,4	27,6	27,5	26,5	26,3	26,4	26,3
Dia 5	27,6	27,5	27,5	26,1	24,3	24,0	24,6	25,6	25,3	24,3	28,6	28,9	28,7	28,2

Figure 7 - Space Medium temperatures without system



	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h
Dia 1	26,4	25,5	25,6	22,8	22,5	25,2	26,0	27,5	26,4	26,9	27,0	28,1	27,5	27,1
Dia 2	27,3	26,5	26,4	27,3	27,1	27,5	24,0	24,1	24,0	24,3	24,7	25,4	26,3	26,8
Dia 3	26,5	26,5	26,3	26,3	26,2	26,3	26,4	26,4	26,4	26,4	26,3	26,2	26,5	26,2
Dia 4	26,4	26,3	26,3	26,5	26,3	26,2	26,5	26,3	26,3	26,3	26,3	26,4	26,4	26,4
Dia 5	26,1	25,7	25,8	25,8	25,9	25,9	26,3	26,5	26,5	26,6	26,6	26,6	26,6	26,6

Figure 8 - Space Medium temperatures with system

4.1 Discussion of the results

In Table 1 it's possible to see the difference between the medium temperatures with and without the system working.

Using the system, it's possible to see that the temperature reduced 8.2% in average value, which was very satisfactory.

Table 2 - Average temperature results

Média de Temperaturas	Dia 1	Dia 2	Dia 3	Dia 4	Dia 5	Média
Sem sistema	**26,5**	**27,0**	**26,5**	**26,7**	**26,5**	26,7
Com sistema	**26,0**	**25,8**	**26,3**	**26,3**	**26,2**	26,2
Diferença	-1,7	-4,3	-0,7	-1,5	-1,1	-1,8

The PPD-PMV model was calculated using those temperatures in a hour basis. The results is find in the Figure 9 , where it's possible to see that with the system working, the conditions are much more near of the thermal comfort zone, than without the system working.

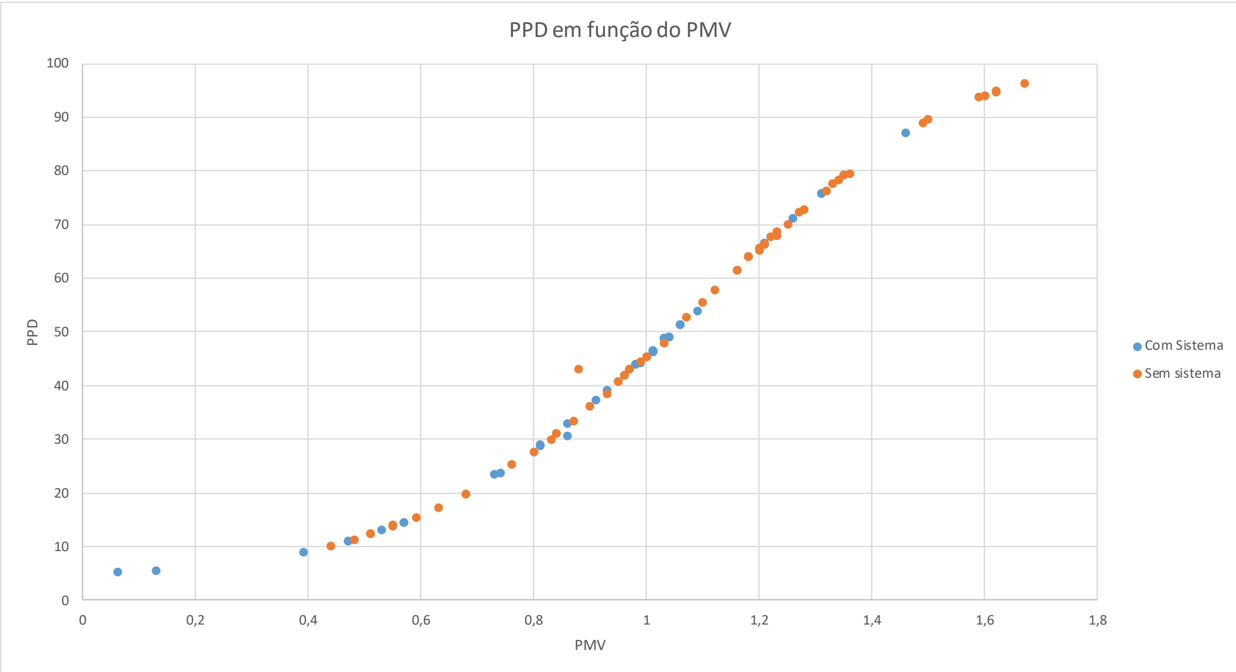


Figure 9 - PMV-PPD Model

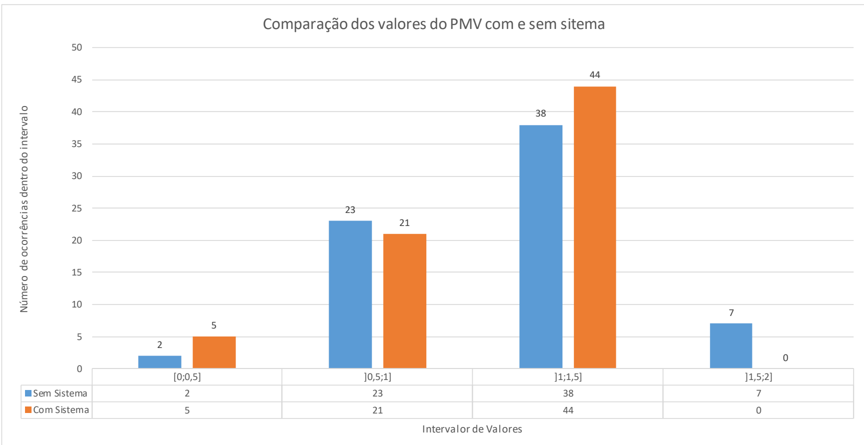


Figure 10 - Comparison between the two systems

5 Conclusion

Due to new laws and new objectives, the automated control solutions are very important and bring a lot of benefits to the building management platform. With this type of solutions, the building efficiency increases, reducing the high dependency from electrical energy, fulfilling the imposed goals.

The thermal comfort zone plays an active role in the wellbeing of the human being. If the comfort is reached, there will be more concentration for the da-by-day activities and for that, the productivity will be larger. Since the studied space didn't had the best solar exposal and infrastructers. It's very important that the climatization system works just fine.

Building Automation is very important and, therefore, has a larger cost (initial and maintenance). The Arduino is a very powerful tool, that has a lot of programming possibilities with reduced costs, comparing with the ones available in the market. It was pleasant to work with the Arduino, because it's open-source. With the project going by, a lot of doubts and question appeared. When doing some research to find a solution, it was very grateful to see that a lot of persons were having the same difficulties and there were a lot of solutions presented. When doing the remote controller configuration there were some difficulties, but there were also a lot of solutions to solve the problems. To integrate a lot of systems in one platform is a very interesting solution to the building maintenance project and using the Arduino, this can be done without having large costs.

The results were good, showing a medium temperature average decrease. Since it was summer, the temperature setpoint was larger, so that the user didn't had discomfort, when leaving the place to the outside. This helped to preserve comfort and energy efficiency, reducing the necessary energy to climatize the space.