Monitoring of environmental parameters at schools for the improvement of academic performance and airborne diseases control

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Abstract. This paper presents a network of environmental sensors developed for the continuous monitoring of variables like temperature, relative humidity, light and carbon dioxide at high schools in Galicia, Spain. The information provided by the sensors can be transmitted in real time and stored at a server for processing and public diffusion. In particular, the carbon dioxide levels serve as an indicator of the air quality to help prevent diseases transmission and improving the welfare and academic performance of students. The development of the meters has been supported by an innovation project granted by the Government of Galicia.

Keywords. Environmental monitoring, electronic sensors, academic performance, disease control.

1. Introduction

Indoor air quality is a factor of great importance for the control of airborne diseases like COVID-19 in educational buildings. A low oxygen level or an excess of carbon dioxide can also cause fatigue and cognitive impairment [1], with serious consequences on academic results of the students and their welfare and health.

On the other hand, the energy performance of educational buildings is strongly affected by factors such as excessive ventilation and heating schedules, in addition to intrinsic ones like construction defects or poor insulation. In order to achieve a balance between these different needs, it is essential to have complete information about the environmental parameters of the buildings with a large number of measurement points and a wide temporal interval. All these data should be centralized and easily accessed for further processing.

To achieve these objectives a team of teachers of two high schools (IES Escolas Proval and IES Val Miñor, Nigrán, Spain) and the local company Hermes Smart Control have started a cooperative project for the development of electronic meters of variables like temperature, relative humidity, light and carbon dioxide levels (Fig. 1).

The project has started during the current situation of COVID-19 pandemic, but it goes beyond this context and seeks the improvement of energy efficiency of the schools and the study of the relationship between the academic performance of the students and the environmental parameters of the buildings.

Our proposal will create prototypes of meters that can be connected to the data network of the schools and will send information continuously to a server (located in each center or external). Other prototypes will store the data in a memory or sd card. In the market there are many equipment [2,3] that can meet these requirements, but they are very expensive (especially if it is planned to install them in all the classrooms) or have bad quality sensors. In many cases the measurements are made over periods of short duration and do not provide sufficient information for a systematic study of the conditions of the environment. The meters should be economical, reliable, with a variable number of sensors and an installation procedure simple enough so that anyone in the schools can do it without high technical qualification.
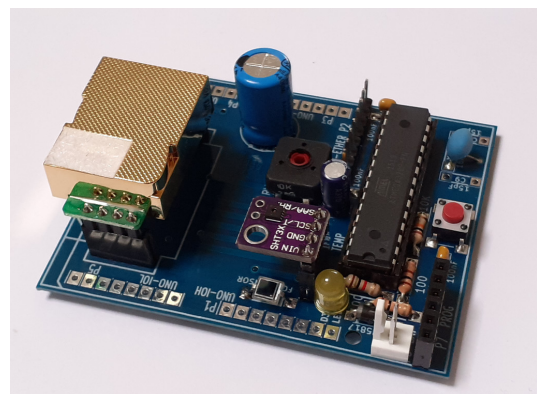

Figure 1. One of the sensor boards of the project

We have planned to develop different prototypes that can adapt to all situations: with and without network interface, screen, keyboard and sd card. The control boards are based in Arduino microcontrollers, Raspberry Pi and others. All of them will have Open Source Hardware and Software to allow an easy reproduction of the project in other institutions.

2. Project Background

The entities involved in the project have a wide experience in innovation. The Department of Electronics of IES Escolas Proval has been developing during the last years several applications with microcontrollers that have been presented at international congresses like HSCI or TAEE [4,5,6]. As an example, the school has designed an electronic weather station that has been providing data during the last fifteen years. This station continues the weather research started at the center from its foundation in 1907, and continued by Prof. Salvador Rodríguez Muñoz since 1987 as an associated center of the Instituto Nacional de Meteorología. The automatic station provides information through its own web page and the data can be easily retrieved. This project received a 2nd innovation award granted by the Instituto Enerxético de Galicia (INEGA) in 2007. The experience gained in the development of this system is the starting point for the current project, because its structure and elements are similar.

The current situation of COVID-19 pandemic has motivated many high schools to start programs of measurement of carbon dioxide concentration. One of this centers has been IES Val Miñor at Nigran (Spain), that at the beginning of this course has purchased meters and acquired data that will help in the definition of the characteristics of the prototypes of the project and its verification.

The industrial partner of the project is the company Hermes Smart Control based at the Bussiness Center of Polígono Porto do Molle in Nigrán. This is a recent foundation company but has a highly qualified R&D team with many years of experience in industrial processes measurement equipments. The company is involved in many projects promoted by Business Factory Auto (IGAPE, Galicia), the Digital Innovation Hub Industry 4.0 (Castilla-León, Spain) or Growth Train (Denmark). The presence of this company in the project guarantees the technology transfer of the results and provides employment opportunities for the students of Vocational Training of IES Escolas Proval.

3. Objectives and Schedule of the Project

3.1. Objectives of the Project

This project has many applications in science and technology educations. Among others, the main objectives of the project are:

- Development of measurement systems of different environmental parameters with data acquisition, storage and communication capabilities.
- Preparation of innovative practical lessons for students of electronics and technology about sensors, data acquisition, communications and programming.
- Technology transfer between educational centers and companies for the development of new systems and products.
- Improve the employment opportunities of the students through the participation in a real R&D experience.
- Acquire a better knowledge about the environmental status and energy efficiency of the educational buildings for the implementation of innovative solutions.
- Promote the interest of students of all levels about environment and energy efficiency.

3.2. Schedule of the Project

The project has been divided into a set of tasks that will be assigned to a team of teachers and students in each center. In some cases the same task can be shared by two teams with a coordination procedure.

Due to the COVID-19 pandemic it was not planned to make presential meetings, instead

we used a variety of communication means like email, message groups and online learning tools like Moodle or others.

The phases of the project are:

1) Initial studies and planning

2) Design and construction of the prototypes

3) Installation of the prototypes and real measurements

4) Evaluation of the results, diffusion and technology transfer.

The tasks related to the design and construction of the electronic prototypes were initially planned for the last months of course 2020-21, serving as practices and small projects for the students of Vocational Training at IES Escolas Proval. But the ventilation regulations established by the educational authorities forced a change in the scheduling in order to obtain information about the air quality, starting these tasks at the beginning of 2021 with the first measurements obtained as soon as february 19th.

The tasks of diffusion and technology transfer were scheduled at the last months of 2021, but have also been advanced for the same reasons. In particular, the partner company Hermes started its own development of dioxide meter to meet the government regulations applied to restaurants and other business.

4. Electronic Prototypes

4.1. Arduino Connected Meter

This meter has been designed to be compatible with Arduino [7] boards and IDE for ease of programming and development. An Atmega328P-PU microcontroller is connected to an ethernet module with a Wiznet W5500 chip [8] which deals with TCP/IP communications and creates a small web server that can be used to check the last data and for configuration. We have chosen a cable connection (RJ45) instead of wifi because it is more widely available in a typical classroom and also for reliability reasons. The ethernet module is independent of the microcontroller board and connects by an IDC-10 flat cable

strip. This configuration allows the acquisition of different modules available in the market.

The selection of the sensors is an important part of the design process. In this case we tried to keep a balance between cost and performance, for this reason we have chosen a Winsen MH-Z19C NDIR carbon dioxide sensor [9], a Sensirion SHT30 temperature and relative humidity sensor [10] and a BPW34 photodiode for light detection [11]. This NDIR sensor has a low cost maintaining the good characteristics of this technology of detection.

The prototype has an usb power connector, what allows the use of many types of power supplies recycled from old phones, tablets or computers.

This prototype has not screen or keyboard to reduce cost. The data can be consulted connecting directly to the micro web server of the meter or on the web page of the project. In the web page each meter has its own space following the same format, that for meter 1 is: http://codos.meteoproval.es/blog/medidor-1.

We have designed our own printed circuit board (pcb) compatible with Arduino Pro-Mini boards that can be connected by usb to a computer for programming and checking purposes. The electronic schematic of the meter is shown in Fig. 2.
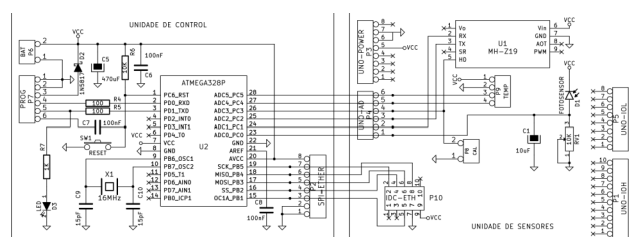

Figure 2. Sensors board schematic

Fig. 3 shows the board design (left) and component map (right). The pcb design is simple enough to make the boards at the high school or send the files to an external manufacturer.
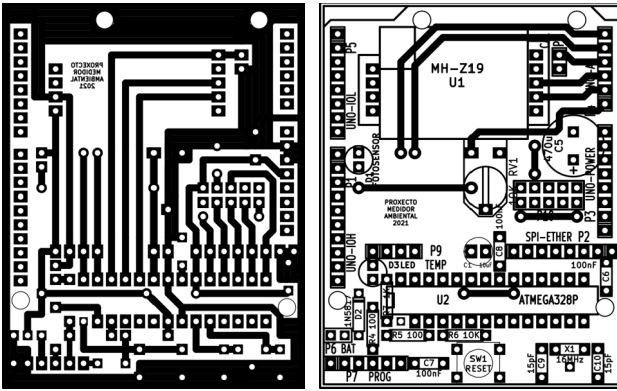
Figure 3. PCB of the prototype: layout and components

Another option is to mount the components using a breadboard or stripboard, using the following diagram made with Fritzing (Fig. 4).
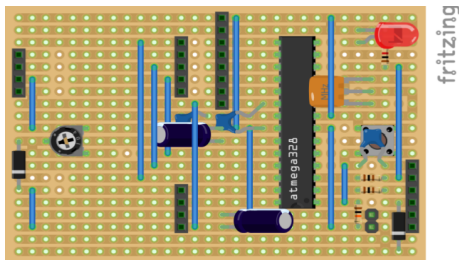

Figure 4. Stripboard schematic

The control program of the board has been made using the Arduino IDE and several libraries for ethernet communications and sensor reading. The code is freely available at the web page of the project [12].

For the carbon dioxide sensor we have used the MH-Z19 library by Jonathan Dempsey [13].

Fig. 5 shows a picture of the finished meter. The case has been made with transparent acrylic for the top and bottom and a metal wire mesh for the sides to allow continuous circulation of surrounding air through the meter.

Figure 5. Finished prototype in its case

The design and construction of the first prototypes has been made at IES Escolas Proval with the participation of teachers and students of electronics degree "Mantemento Electrónico". Fig. 6 shows the students during the soldering and assembly of the boards.

Figure 6. Assembly of boards at IES Escolas Proval

4.2. Ventilation educational model

The objective of the educational model is to be able to control a ventilation system for two rooms. The opening of two gates controlled by a servomotor and the speed of an air extractor will be controlled. In this way the air flow will be controlled and therefore the time in which the room is ventilated.

In addition, the graph of the main system variables can be observed locally on a 3.4 inch touch screen and on a data server that will allow studying the history of the stored data. As system variables, the CO2 concentration of each cabin, the speed of the extractor and the condition of the vents will be measured. Fig. 7 shows the complete assembly of the system.
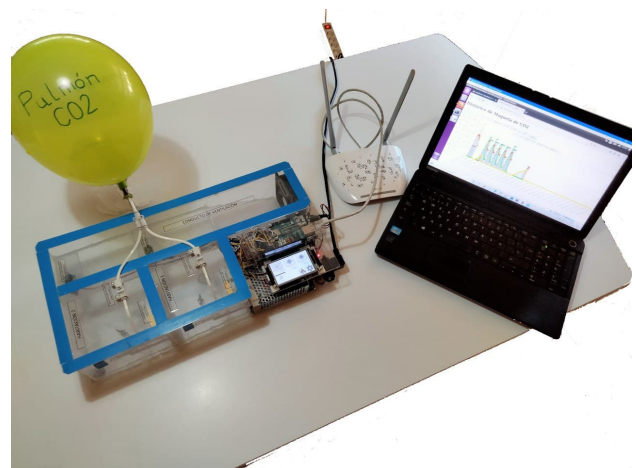

Figure 7. Assembly of the ventilation model

An interesting feature of the educational model is that the control cycle is repetitive. If we keep the CO2 valve in the same position, the CO2 concentration rate is always the same. This allows testing various speed control algorithms: on-off control (Fig. 8), proportional control, PID control and others.
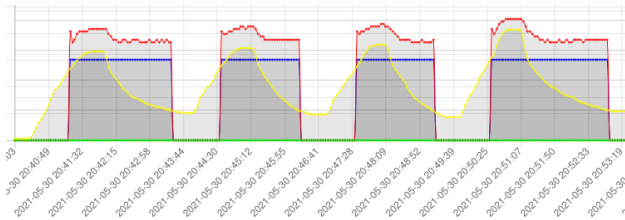

Figure 8. Control algorithm graph

The control equipment chosen is an Arduino Mega 2560 [14]. It has enough memory to handle a large amount of data. It also allows testing multiple hardware scenarios. This facilitates the scalability of the prototype.

The model will have communication to be able to store the data in a MySQL-Apache server that allows visualizing in a graph the CO2 variables, the motor speed and the status of the grids. An Ethernet Shield card will be used for this. This will allow the Arduino to connect to the data server network.

To be able to control the model locally and to be able to see the graphics, a touch screen will be used. In this case, Nextion's Enhanced model will be used [15]. This screen allows you to efficiently refresh up to the simultaneous measurement of four variables. In addition, it incorporates a real time clock (RTC) that ensures the time by means of a button battery. It allows to detail in the graph the temporary indication of the RTC.

The CO2 sensors are of the NDIR type with a measurement range between 400 and 2000ppm. The model is the Winsen´s MHZ19C [9]. These sensors allow reading through serial communication and have a calibration pin.

The extractor is a 12V fan used for air cooling of computer equipment. It is a motor that allows speed control. Particular care must be taken with the orientation for it to properly exhaust air. It also has hall effect sensors that allow to control revolutions over time and

therefore speed. The pinout of this type of device (Fig. 9) depends on the manufacturer but we can find fans with three or four wires.
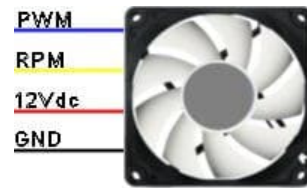

Figure 9. Pinout of a typical computer fan

In Fig. 10 you can see the connections of the elements that are part of the system. A video tutorial that shows the different parts of the assembly and the control procedure is available in galician language [16].
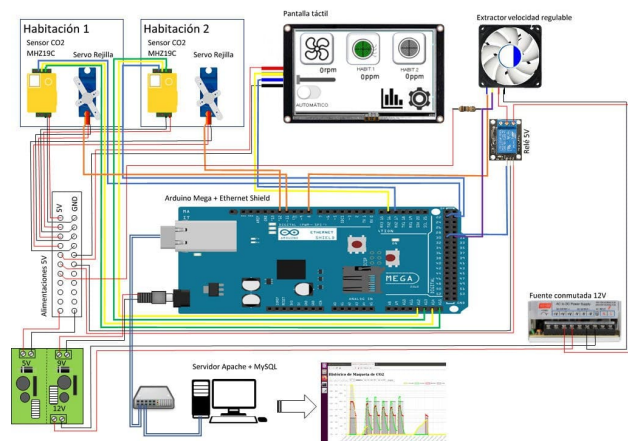

Figure 10. Ventilation system schematic

The data server is based on free software. The software has been installed on a Ubuntu16 version. The option to choose this version of the operating system is due to its low hardware requirements.

In order to store and exploit the data provided by the Arduino kit with Ethernet Shield sensors, we must install a LAMP server. The installation of this server is carried out basically by installing the Apache web server packages, a MySQL database manager and the php language to be able to program the graph and access to the database data.
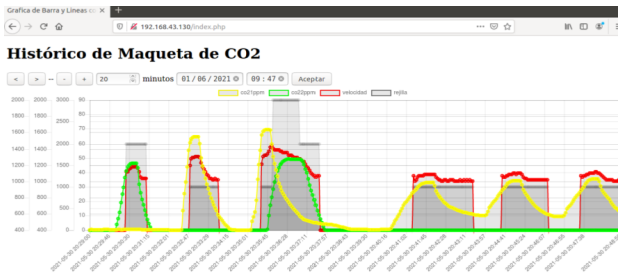
Figure 11. LAMP server data presentation

From the graph page (Fig. 11) you can browse the data and view a window with more or less amounts of them.

Chart.js package has been used to program the graph which allows its free use under the MIT license.

4.3. Raspberry Pi Prototype

The Technology Department of IES Escolas Proval is developing a prototype based on a Raspberry Pi 2 [17]. The use of this hardware increases the cost of the CO_2 meter compared with Arduino boards, but it simplifies the presentation of the data through a touchscreen. The software used was the programming IDE for Processing (PDE), running on Raspbian operating system.

The values provided by the MH-Z19C sensor are read using its PWM output. Data are captured with a frequency of one sample by minute.

These values are sent to the internal server of the educational center and also to the Thinkspeak website [18]. An interesting functionality is the use of a Telegram chat to read the last message. The user of this chat can send commands from a mobile phone, tablet or computer. Currently it accepts two commands: *State* and *Calibration*. The first command indicates the system to respond to the chat with the level of CO_2 and temperature in real time. The second commando initiates the calibration procedure of the sensor. Bidirectional communication with Telegram allows the setting of high or low CO_2 level alarms or the indication of an abnormal operation of the equipment with a few lines of code. Fig. 12 shows an example of use of the Telegram interface.
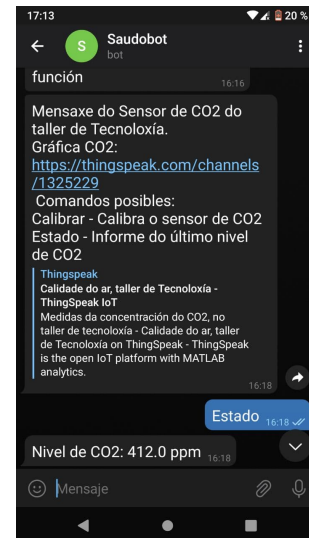

Figure 12. Example of Telegram message

The use of Raspbian operating system allows the remote programming of the prototype via a VNC client. For the connection of analog sensors such as the LM35 temperature sensor it was necessary to use an external analog to digital converter, since the Raspberry Pi has no analog inputs. For this purpose we have used a Microchip MCP3208 integrated circuit. This prototype is installed in the Technology workshop of IES Escolas Proval (Fig. 13).
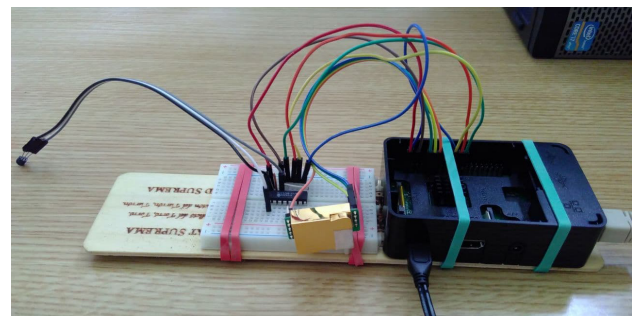

Figure 13. Raspberry Pi prototype

4.4. Qair Hermes Meter

The company Hermes Smart Control is developing its own carbon dioxide meter named Qair. The meter has a screen that indicates the level in ppm and a three colour code that allows users to easily check the status with a quick view. Its shape remembers a 'vieira', the well known icon of the Way of St James and also a symbol of galician gastronomy. Fig. 14 shows a picture of the first version of the meter, that has been presented to the media in May 2021 [19].

Figure 14. Qair meter designed by Hermes Smart Control

5. Preliminary results

Since the first measurements in february we have installed a total number of 18 meters in three high schools of Val Miñor (IES Escolas Proval, IES Val Miñor and IES Primeiro de Marzo of Baiona). The data acquired during these months permits to make a first analysis and provide information for later stages of the project.

5.1. Data acquisition and analysis

As an example of the results obtained we present an analysis of the data obtained during an exam day at IES Escolas Proval. In this date (May 3rd) the ventilation was insufficient and carbon dioxide levels achieved levels as high as 1680 ppm at 9:34h, 1610 ppm at 12:45h and 1213 at 17:16h. The mean level during the morning was 1005 ppm (8:45-14:30h) and during the afternoon was 813 ppm (16:00-18:10h). This data exceeded the recommended values and probably had a deep impact on the welfare and academic performance of the students. Fig. 15 shows the graphical representation of the carbon dioxide levels in this date.
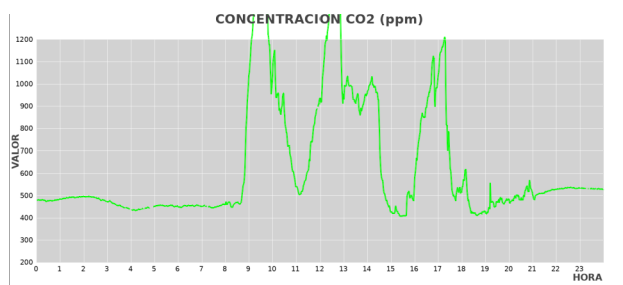

Figure 15. CO2 levels on May 3rd

5.2. Comparison with reference meter

An important part of the project is the comparison of the prototypes with a reference meter which gives information about the quality of the measures obtained. For this purpose we acquired an Extech CO-260 [20] carbon dioxide meter (manufactured by FLIR). This meter has a Senseair K30 sensor which has better characteristics than Winsen MH-Z19C. The results of these comparison are represented in Fig. 16 (evolution during and interval of 30h) and Fig. 17 (correlation between measurements). Also the regression coefficients have been calculated showing a good coincidence between the two types of meters.
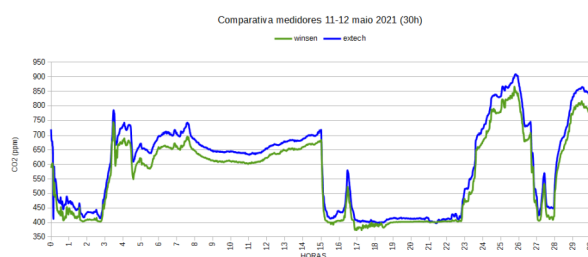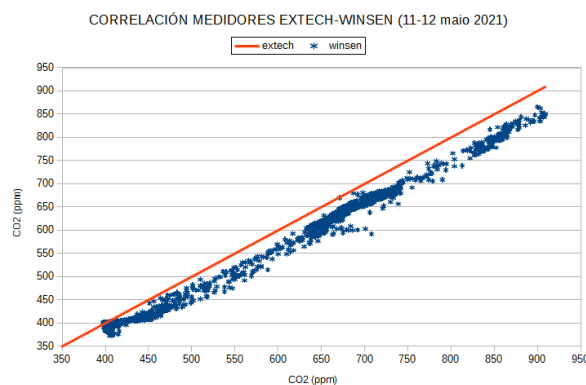

Figure 16. Time comparison of meters

Figure 17. Correlation of measurements between meters

5.3. Calibration procedure

NDIR sensors have automatic (ABC) or manual calibration procedures that can be applied according to the working environment. For this project we have chosen the manual calibration because in a typical classroom there is no guarantee that air renovation achieves the base level of 400 ppm. This means that calibration should be revised at least every

month (or two weeks if possible).

Each set of new meters have been calibrated before placing them in the classrooms. Fig. 18 shows a representation of the measurements of the meters before and after the calibration procedure, showing a good convergence of the values.
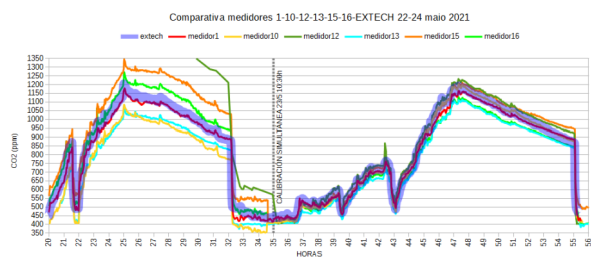

Figure 18. Calibration of meters

Fig. 19 presents the calibration of a set of meters at the same place, with all the meters connected to the same switch and sending data to the server at the same time.

Figure 19. Calibration setup

6. Educational Activities: the COVID Sentinels of Val Miñor

In the next paragraphs we will present some of the activities carried out in different stages of the project.

6.1. Introduction

Since 2020, March 13th the spanish educational institutions had to adapt to a new situation of "emergency remote learning". The current course 2020-21 has been a success not only by the low infection rates but the ability to take educational advantage of this circumstances.

One result of these efforts has been the cooperation between IES Val Miñor and IES Escolas Proval and the set of activities that we have carried out, both individually or as a joint effort.

At IES Val Miñor this project started with the departments of History and Physics, but during the course many other teachers were involved: Biology, Technology, Mathematics, Galician Language, French and others.

Some circumstances boosted the development of the project: the students of 1st grade of ESO were expected to work in projects and the department of Physics had started a study of CO_2 measurements with commercial meters with the cooperation of Geography and History teachers.

The work of the students was divided in three main themes to let the students understand the current situation and its historical context: the Globalization, the Climate Change and the Global Pandemics.

- The Globalization: we have planned activities to understand its influence in economics, politics, culture...
- Climate Change: study of the meteorology and climate and its influence in our life.
- Global Pandemics: analyse the "Greatest Killers in History" that were not persons but virus and bacteria: the Black Plague, Spanish Influenza and others. Also will be studied its relation with the evolution of world population through activities like population pyramids and others.

6.2. Preliminary works

At the beginning of course 2020-21 the management and Physics department of IES Val Miñor started a program for the analysis of the carbon dioxide concentration in the classrooms as an indicator to adopt ventilation measures during school hours.

Due to the high cost of the commercial meters and the low budget of educational centers, it was decided to acquire a single meter for a total number of 20 classrooms and about 400 students. The solution adopted was

to periodically move the meter from classroom to classroom. This solution did not allow a rigorous study of the data, attending to environmental conditions (humidity, temperature...) and people (number, age, sex, weight...) that influence the measurements. After a few days it was clear the need to make periodic measurements in all the spaces to contrast the results.

At this point it was proposed to participate in the innovation project with IES Escolas Proval. The installation of four new meters allowed to make a selection of classrooms attending to their orientation, number of students and distribution of doors and windows.

An important contribution to the project was the elaboration of different documents and materials for the proper installation and working conditions of the meters. These documents also served as educational information for the students that cooperated in the project.

- INSTALLATION MANUAL: Physical conditions of the classroom and position of the meter. As general conditions, half of the windows should be always opened, blind opened as much as possible except in case of rain and the door always opened. The meter should be placed far from the door or windows. If it was on the teacher's table it should be far from air flow from the computer fan and the students (and the teachers) should avoid to be close to the meter. Some students blowed to the meter as a joke, but soon they discovered that it was registered in the graphs and stopped doing it.

- DATA REGISTER: the students had to make each day a document with the following information: number of meter, classroom, responsible's name, hour, number of students pero hour, weather conditions and any other information related to the measurements (Fig. 20).
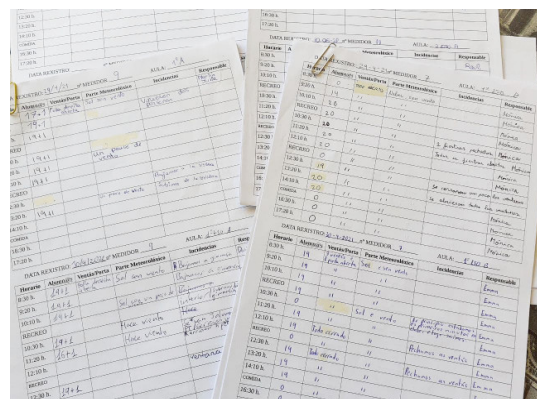

Figure 20. Example of data registers

- INSTALLATION TOOLKIT: in a typical high school it is not easy to find the materials needed for the installation and connection of the meters. We created a "toolkit box" (Fig. 21) with scissors, ties (to keep the cables together), 5-meter long usb cables and ac cables (many times the mains sockets are not in the best place) and the data register sheets. These kits were placed at the teacher's room, where there is (almost) always people to control the material and give it to the students.

Figure 21. Installation Toolkit

6.2. Classroom Measurements and calibration

Before starting with the measurements all the teachers were informed by messages and cartels in the classrooms. But the most important task before starting was the selection of the human resources that would be in charge of the measurements: the students. They

shoud take care of the meters and detect any event that could affect the measurements. Without their cooperation the information provided by the meters would lack important data to understand what was happening.

The process of registering data, analysis and improvement proposals was carried out by 25 students of all the groups classroom that voluntarily decided to participate, to whom we would like to thank for their cooperation. It was needed to create a schedule to assign days to all the participants. Since then they were in charge of registering the daily data, passing the sheets to the following student and at the end of the week they give them to the teachers. The students also watched the data and graphics stored in the web of the project. This information allowed to detect failures, need for calibration and jokes of some students that distorted the measurements.

Fig. 22 shows one of the meters in a classroom at IES Val Miñor.

Figure 22. Meter in one of the classrooms

The calibration process of the meters was reserved to the teachers of the project because it needed to access restricted data and characteristics of the meters.

The calibration should follow the strict requirements indicated by the manufacturer of the dioxide sensors. The meter must be in clean air (for example outside the window), with constant temperature, without direct sunlight and no air flows nor people close to the meter. All these conditions should be kept for a minimum time of 15 minutes. For this reasons it can only be made in the mornings during school breaks or in the afternoon when there are not classes.

The meter should be connected to the network and from a computer must be checked the current measurement until it maintains a stable level. At this moment it must be activated the calibration option in the internal server of the meter to start the internal algorithm. After that it should be checked again to verify that now the level coincides with the atmosferic base level (about 400 ppm). If there is any problem the calibration process should be repeated until it is correct.

6.4. Final activities and results

The main diffusion activities (congresses, participation in exhibitions and science fairs) were planned for the last months of 2021 and 2022. This course we made an online photograph contest that was organized through the virtual classrooms of both high schools. The contest had the advantage that all the students were already registered in the online tools and had been trained to use its resources. There was a few participation but we expect to repeat the experience with higher success. The information about the contest and winners have been published in the web pages of both centers [21,22]. Fig. 23 shows the information at the bulletin board of IES Val Miñor and Fig. 24 shows the winners at IES Escolas Proval.

Figure 23. Announcement of the contest and winning photographs

Figure 24. Award winners at IES Escolas Proval

7. Conclusions

In this paper we have presented a cooperative project made by two spanish high schools, IES Escolas Proval and IES Val Miñor and the company Hermes Smart Control. The project was aimed to the development of environmental meters with different sensors and capabilities. Some prototypes have been already made and are acquiring and storing data to provide information about the ventilation of spaces and to improve the welfare and academic performance of students. The company Hermes is developing its own meter for restaurants and other business.

Many students of the educational centers were involved in the project and were responsible for the meters, the data registers and external conditions. This activity helped them to became aware of their own skills and feel valued.

8. Acknowledgements

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