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Chapter 4
Air quality monitoring device to optimize working and learning conditions

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Abstract: Social awareness of the quality and cleanliness of the air around us is growing every year. Especially during the heating season, the media are discussing these issues. Measures to reduce the emission of its pollutants are undertaken more and more often. Undoubtedly, its condition affects our health and well-being. Running a company, not only industrial one, is associated with process optimization in order to reduce expenses and maximize profits. In the case of mental work, its effectiveness will be largely influenced by well-being, and therefore the quality of air in the workplace. It happens similarly in a place of study, where the results are dictated by the conditions in which one is staying. The design of the air monitoring device presented in the article allows for the analysis of working and learning conditions in order to take actions to improve them. Air quality monitoring device to optimize working and learning conditions.

Keywords: air quality, carbon dioxide, IoT, home automation

Introduction

In recent years, there has been an increase in public awareness of air cleanliness and quality. The media more and more often discuss the issues of smog, exhaust gases, pollution caused by technological processes or the use of harmful materials and substances in various areas of life. The popularization of these issues results in increasing public interest in the impact of the environment in which they work or live on their health. The growing interest in the subject of electromobility, electric and hybrid cars and issues related to renewable energy sources is similar – they all are to reduce environmental pollution.

Nowadays, in every branch of the economy, there is an attempt to optimize processes or activities. The goal is to maximize the effects and profits with minimal effort or at the lowest possible cost. At the beginning of the 20th century, the establishment of the International Labour Organization resulted in the reduction of the working day to 8 hours [1], which was largely due to the dynamic development of industry. The automation of technological processes allowed for the reduction of employees, shortening their working time, while offering similar or better results.

Currently, in developed countries, enterprises often based on intellectual value play a significant role in the economy. The basis for its creation is human intellectual work – not physical. The effectiveness of its results will be influenced by the ability to concentrate, and therefore the environmental conditions of the workplace – including air quality – are of key significance. In many cases, in this area of the economy, working hours have a smaller impact on performance than workspace conditions.

Taking into account all the above-mentioned factors, there is a need for a technical solution enabling air quality testing in a working or residential space so that it could be available to a wide group of recipients, at the same time offering reliable measurement results. In addition, the device would enable integration with existing home automation systems (to control air conditioning, heating, mechanical ventilation). At the same time, it would ensure the scalability of the created system and would allow for the collection and sharing of results in order to conduct research so as to be able to effectively optimize the work.

Defining air quality

Air quality is a slogan that is increasingly appearing in the public awareness. The market offers more and more devices in the form of air purifiers, which are designed to reduce small particles. At this point, there is some doubt as to what, and specifically by what parameters, defines air quality.

The most popular air quality index is AQI (Air Quality Index, Table 4.1) [2]. It is worth noting that the AQI indicator has different varieties depending on the country or region [2, 4, 5, 6]. It determines the effect on health on the basis of concentration values of individual substances [3]. According to the information of the Chief Inspectorate for Environmental Protection (Poland) [4], these factors are:

- solid particles PM 10 and PM 2,5,
- O_3 (ozone),
- NO_2 (nitrogen dioxide).
- SO_2 (sulphur dioxide),
- C_6H_6 (benzene),
- others.

The conditions in which one stays, lives or works affect the well-being of a person. The effectiveness of the tasks performed, especially during mental work in closed rooms, will clearly depend on the conditions prevailing there. Research shows that air temperature, its humidity, pressure and the concentration of carbon dioxide in it influence the well-being of a person [7, 8, 9]. Ultimately, these factors will affect the quality of work.

TABLE 4.1. AQI values and determination of air quality [2]

Daily AQI Color	Levels of Concern	Values of Index
Green	Good	0 to 50
Yellow	Moderate	51 to 100
Orange	Unhealthy for sensitive groups	101 to 150
Red	Unhealthy	151 to 200
Purple	Very Unhealthy	201 to 300
Maroon	Hazardous	301 and higher

Based on the above information, it can be observed that various indicators or factors can define air quality. The aim of the project is to optimize working and learning conditions, hence the measurements are oriented towards closed spaces. Temperature, humidity, pressure and CO_2 concentration were assumed as measured values.

Measurement of non-electrical values

The basis for the effective operation of a measuring device is the appropriate selection of transducers that enable the measurement of selected physical quantities. In the selection it is important to follow the criteria set for the project, such as price, accuracy, size and working conditions.

Currently, there are various systems available on the market to measure the concentration of carbon dioxide. They differ in the method of measurement, price, size or consumed energy.

The most popular sensor groups are listed below:

- MOx (Metal Oxide) [10] – semiconductor sensors, have small dimensions and low price, their main disadvantage is high energy consumption (instantaneous, during the heating of the metal oxide layer) and the fact that the concentration of carbon dioxide is estimated using algorithms, the result will depend on the presence of volatile organic compounds, these sensors are characterized by poor time stability;
- NDIR (Nondispersive Infra Red) [11] – an example of spectrometric measurement, characterized by high accuracy and stability over time, the disadvantage is high energy consumption, relatively large dimensions (compared to other solutions mentioned) and high price;
- Sensors using photoacoustic effect [12] – sensors with small dimensions, high accuracy, average energy consumption, the disadvantage is the high price and availability (new solution on the market).

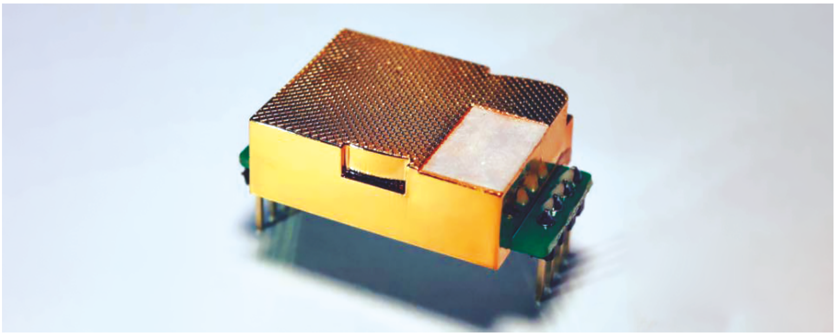

FIGURE 4.1. **NDIR sensor MH-Z19C [13]**

Based on the features of the above groups of sensors, a sensor was selected to measure the concentration of carbon dioxide. The MH-Z19C sensor (Fig. 4.1) in the form of a Winsen module was selected. It is a sensor from the NDIR group with a measuring range of 400–5000 ppm, accuracy of ±50 ppm + 5% of the read value and declared service life of over 5 years [14].

As in the case of the sensor for measuring the concentration of carbon dioxide, an appropriate system for measuring other values specified in the assumptions was selected in accordance with the criteria. A decision was made for a single-chip sensor BME280 by Bosch [15], which offers the simultaneous measurement of temperature, humidity and pressure. This procedure allowed for the reduction of costs (the need to purchase one chip) and simplification of the electronic circuit.

Device design

The design of the device has been developed on two levels: electronic and software. Each of them meets certain criteria and complements each other at the same time.

Due to the fact that the device is intended to work indoors, it is important that its dimensions allow for its installation in any place, without the need to meet special installation conditions. In addition, taking into account the fact that it would be installed in existing buildings, the advantage will be the fact that there is no need to make a dedicated wired installation.

As shown in Fig. 4.2, the device consists of 4 main blocks. The ESP32 microcontroller was used as the central control system. This 32-bit chip equipped with Wi-Fi [16] functionality is responsible for peripheral operation, data acquisition and wireless connectivity. The choice of Wi-Fi as the transmission medium was dictated by the widespread presence of infrastructure and its low cost. The data is saved on the memory card. The measurement results are displayed on the screen. The ability to communicate with a computer via the USB interface allows to update the software or access data.

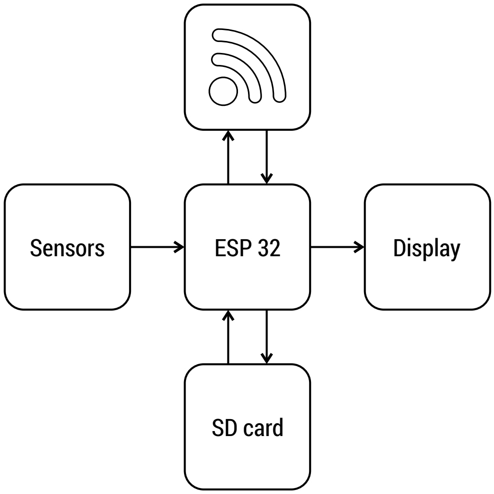

FIGURE 4.2. Block diagram of the most important modules of the device

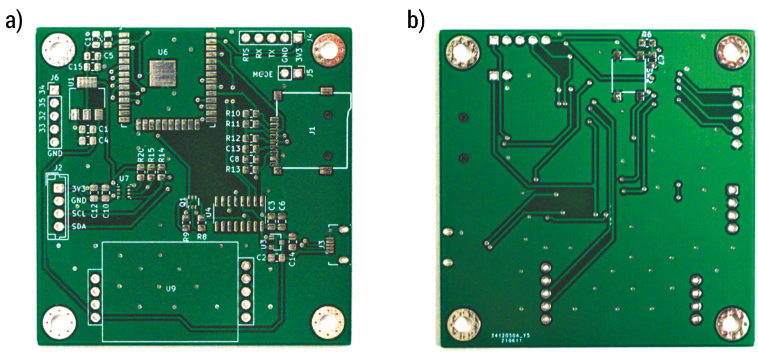

FIGURE 4.3. Printed circuit board, a) top layer, b) bottom layer

The used microcontroller, thanks to its peripherals, provides a wide range of functionalities. An efficient 32-bit processor with Wi-Fi communication allows you to run a web server on the device. This allows remote access to the device. By these means it is possible to view the measurement results via a web browser, configure the device or download the collected data for in-depth analysis. Saving data on the memory card in the form of .csv files allows for easy analysis with commonly used software. In addition, with the help of the network capabilities of the system, it can be connected to home automation systems and more. The MQTT protocol [17] can be used for this purpose.

Having a server with an MQTT broker allows for collecting data from the sensor network (Fig. 4.4). This approach fosters the use of devices in many rooms of an office, house, school or university. However, data can be monitored from one point, without the need to: access a given network or physically access the device. The centralization of information enables them to be easily used to control building automation systems, in this case air conditioning, heating and mechanical ventilation. Since the network consists of individual devices in each room, it allows for zone control and optimization of resource use as well as individualization of operation depending on the requirements set in a given place.

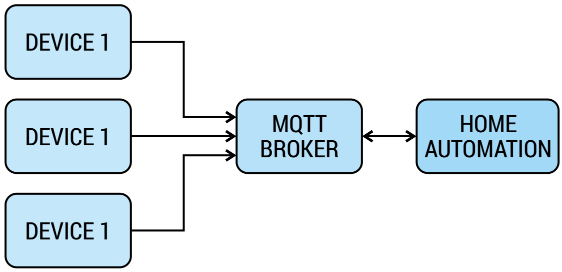

FIGURE. 4.4. Diagram of connection of sensor network with MQTT broker

Results analysis

The best way to verify that the device is working properly is to test it in a practical way. The prototype of the system was tested in various environmental conditions. This allowed for the correct functioning of the device to be confirmed and the results to be confronted with the theory.

The first measurement (Fig. 4.5) was made as a reference measurement. The measurement was made outside the building in an open area in winter. Its purpose was to verify the correct operation of the CO_2 concentration sensor.

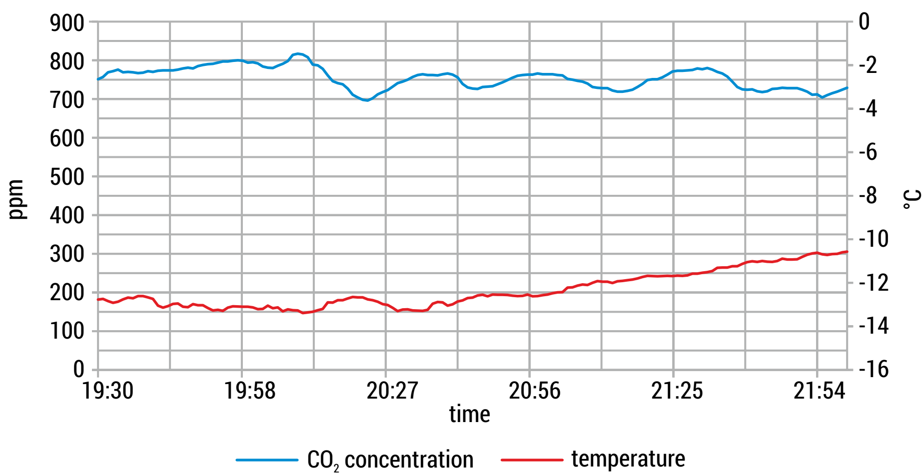

FIGURE 4.5. Reference measurement

The reference measurement (Fig. 4.5) is the reference point to verify that the device is working properly. Currently, the concentration of carbon dioxide in the atmosphere is around 415 ppm (2020) according to the data of Earth System Research Laboratories [18]. Therefore, taking the measurement outside should result in a similar result. The value of CO_2 concentration is influenced by atmospheric conditions, time of day, air pollution, buildings, terrain or time of the year [19, 20, 21].

The full measurement (Figs. 4.6, 4.7, 4.8) was made in a computer lab with an area of about 70 m^2 during a block of classes in which 16 people participated. In the middle of the measurement, there was a break and the room was aired. During the classes, the windows in the room were closed. The measurement was made in winter.

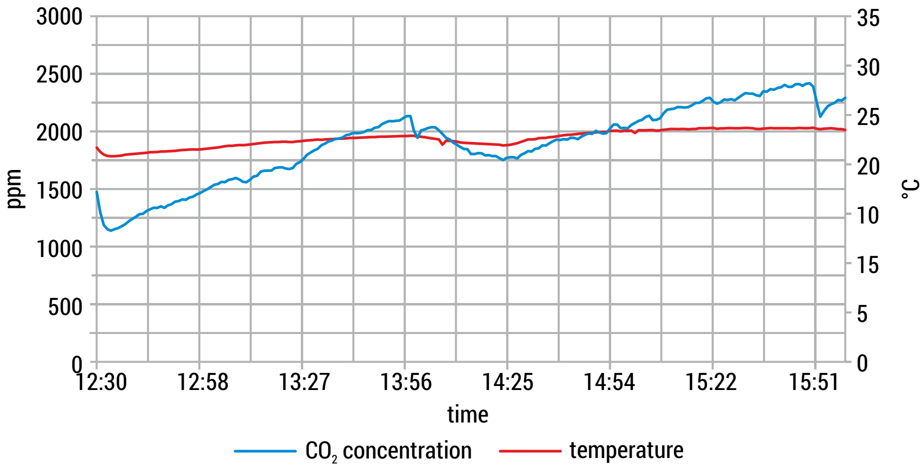

FIGURE 4.6. CO_2 and temperature measurements made during the lesson

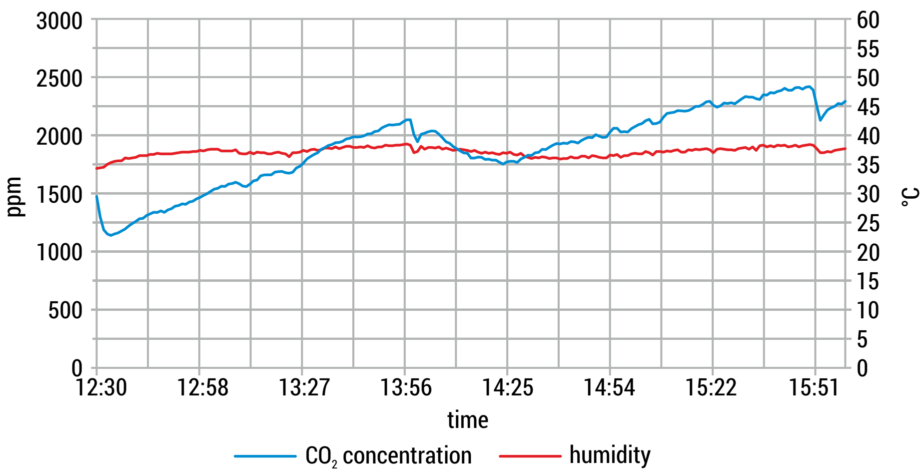

FIGURE 4.7. CO_2 and humidity measurements made during the lesson

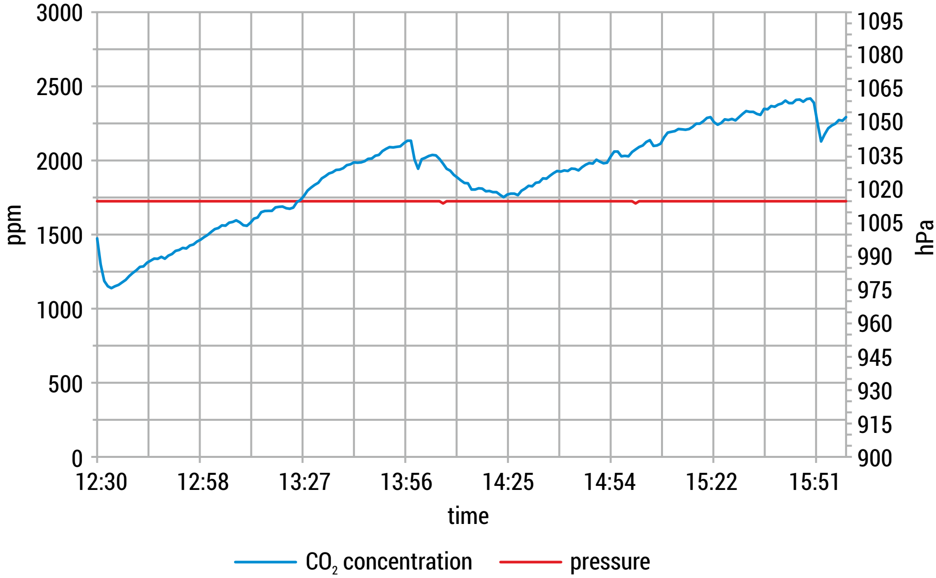

FIGURE 4.8. CO_2 and pressure measurements made during the lesson

After starting the device, the concentration of carbon dioxide suddenly dropped, and then gradually the concentration of carbon dioxide increased until 1:56 pm. After this period, a decrease in concentration was visible, at that moment there was a break between classes. The decrease lasted until 2:25 pm, until the beginning of the next block of classes, after which the value increased again, reaching a concentration of about 2500 ppm. Shortly after the end of the classes, one could notice a decrease due to airing the room. Figure 6 shows a slight correlation between the increase in CO_2 concentration and the increase in temperature. It is worth noting that this is a computer lab, and the measurement took place during the heating season. A similar situation is visible in the case of Figure 7, where there are visible increases in humidity along with an increase in the concentration of carbon dioxide. Pressure values were constant. During the entire measurement period, the fluctuations ranged from about 1100 ppm to about 2500 ppm, the average value was about 1900 ppm. It is assumed that concentrations above 1000 ppm indicate unsatisfactory, and above 2000 ppm – poor air quality [7].

Summary and conclusions

The article presents the design of an IoT device for air quality measurement in order to analyze environmental conditions and integrate with building automation systems. Sample measurement results are shown. Moreover, an analysis of the obtained results was carried out.

The presented solution allows for the measurement of carbon dioxide concentration, temperature, humidity and pressure. Thanks to the built-in Wi-Fi connection, it is possible to integrate the device with building automation systems to control mechanical ventilation, heating or air conditioning. The device allows to collect data on a memory card, which can be used for long-term analysis.

The presented results from the classroom show unsatisfactory conditions during the classes, negatively affecting the comfort of the participants. The simplest solution would be to ensure a continuous exchange of air by constantly opening the windows. Unfortunately, the possibility of airing the room is limited by the weather conditions outside (low temperature, humidity). Alternative solutions in the form of mechanical ventilation with recuperation (heat recovery) require an installation that may not be possible to make or may be expensive.

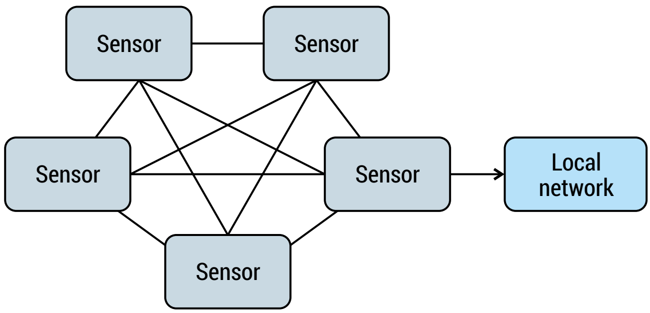

FIGURE 4.9. Example connection structure of devices working in mesh network

The applied solutions allow for the implementation of mesh technology (Fig. 4.9) [22] in order to create a scalable measurement system. This reduces dependence on the range of the available Wi-Fi network. The ESP32 microcontroller also offers access to Bluetooth [16] technology, also in mesh technology. New systems from the ESP32 family by Espressif [23] will also offer connectivity using technologies dedicated to IoT applications. These technologies are Zigbee [24] and Matter [25]. It is also possible to expand the device with additional sensors in order to monitor additional environmental parameters. The used efficient control system, together with the availability of many programming tools from the chip manufacturer, allows for the implementation of various network protocols. This enables integration with various systems available on the market. The research will be continued as the project develops, taking into account the current and future technological achievements and the possibilities of data analysis.

Streszczenie: Świadomość społeczna odnośnie jakości, a zarazem czystości otaczającego nas powietrza rośnie z każdym rokiem. Szczególnie w okresie grzewczym media poruszają te kwestie. Coraz częściej podejmowane są działania mające na celu ograniczenie emisji jego zanieczyszczeń. Niewątpliwie jego stan ma wpływ na nasze zdrowie czy samopoczucie. Prowadzenie przedsiębiorstwa, nie tylko przemysłowego,

wiąże się z optymalizacją procesu, tak aby ograniczyć wydatki, a zmaksymalizować zyski. W przypadku pracy umysłowej, na jej efektywność, będzie wpływać w dużej mierze samopoczucie, a zatem jakość powietrza w miejscu pracy. Analogicznie bywa w miejscu nauki, gdzie rezultaty podyktowane są warunkami w których się przebywa. Przedstawiony w artykule projekt urządzenia do monitorowanie powietrza, pozwala na prowadzenie analizy warunków pracy oraz nauki, w celu podjęcia działań ich poprawiających. Urządzenie do monitorowania jakości powietrza w celu optymalizacji warunków pracy oraz nauki.

Słowa kluczowe: jakość powietrza, dwutlenek węgla, IoT, automatyka domowa

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