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Research paper

Application of the internet of things (IoT) technology for controlling air purification in the apartment

Wojciech Drozd[1], Marcin Kowalik[2]

Abstract: Persistent air pollution (SMOG) in large cities in countries based on energy and coal heating is a serious and growing problem. Improving air quality is currently the main challenge for the metropolises of Central and Eastern Europe. Despite intensive efforts, the average annual concentration of PM2.5 in this area exceeds the standard recommended by the World Health Organization (recommended standard – 25 µg). Data from environmental institutions show that, for example, in Kraków (Poland), the number of days with PM 2.5 concentrations drastically exceeding the permissible standards in the last year was 96. The article describes the method of controlling air purification in the apartment using automation devices, control software and applications available for smartphones, tablets and personal computers. The presented solution uses technologies that can use free (alternative) software, extending the functionality of devices and increasing the flexibility of the control system. The main goal is to maximize the comfort of home users and to minimize the cost of electricity consumption. Additionally, the existing air cleaning devices are adapted to the needs of the air cleaning control system.

Keywords: Internet of Things (IoT), housing construction

[1] Assoc. Prof. PhD. Eng., Cracow University of Technology, Faculty of Civil Engineering, Division of Management in Civil Engineering, ul. Warszawska 24, 31-155 Kraków, Poland, e-mail: wojciech.drozd@pk.edu.pl, ORCID: 0000-0001-7978-2268

[2] M.Sc. Eng., Cracow University of Technology, Faculty of Civil Engineering, Division of Management in Civil Engineering, ul. Warszawska 24, 31-155 Kraków, Poland, e-mail: marcin.kowalik@pk.edu.pl, ORCID: 0000-0001-9679-8835

1. Introduction

Residential This article presents the problem of controlling air purification in an apartment with the use of modern automation devices, such as:
- PM 2.5 laser suspended dust concentration sensors, WIFI communication,
- temperature and humidity sensors with Bluetooth technology,
- intermediary bridges integrating the communication of sensors and actuators,
- air purifiers with HEPA filters and humidity control options,
- control devices in the form of tablets, smartphones and computers with installed applications to manage and control the system.

The installation uses:
- 1 PM 2.5 dust concentration sensor external,
- 3 independent H / T sensors,
- 3 internal PM 2.5 dust concentration sensors,
- 3 Bluetooth – WIFI bridges,
- 1 WIFI bridge – Internet,
- 4 control devices (2 smartphones, 1 tablet, 2 computers),
- 3 air purifiers.

This solution was proposed and implemented on the basis of data obtained from external and internal PM2.5 dust concentration sensors. Information on air quality was collected over a period of 1 year. The World Health Organization defines the standards for suspended dust concentrations at the following level [1]:
- PM10 – 50 µg/m^3,
- PM2.5 – 25 µg/m^3.

Sample readings from the external sensor revealed a very large excess of the current standards (Fig. 1).

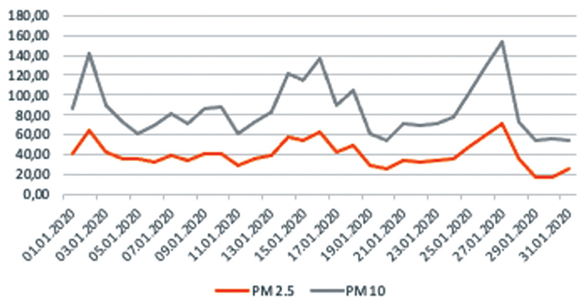

Fig. 1. Dust concentration PM 2.5 and 10 on January 2020 at 19 pm. Source: own

The hardware solution described in the article is an innovative contribution to the methodology of conduct in the implementation of a cheap solution improving the comfort of staying in residential premises. The course of action, the selection of devices and materials for the construction of an autonomous air quality improvement system is shown. An example of an installation enabling the adaptation of existing flats to adapt to the standard requirements in the scope of PM10 and PM 2.5 dust concentrations was presented.

2. Description of the apartment

The heating installation is in the apartment of approx. 111 m^2, in a building completed in 2005. The building was constructed in the technology of a reinforced concrete frame, with ceramic filling, in the form of MAX blocks and 20 cm thick mineral wool insulation. The location of the apartment is on the third floor of a 5-store building, with east-west windows having modern airtight window joinery.

3. Automation devices

3.1. Outline of existing solutions

Currently, there is a negligible number of flats adapted to air purification and filtration on the housing market. This is especially true of older buildings where such systems have not been installed. There are, of course, buildings with a closed air circulation using expensive system solutions in the form of central air conditioning, heat exchangers (recuperators) and installations for distributing clean air in the facility. However, these are either office buildings (specially designed for such activities), or new buildings, in principle, using automatic media control available to users (Building Management System BMS) [2].

Retail solutions include single air purifier installations containing PM10 and PM2.5 particle sensors or devices with a separate pollutant detector. There are currently no open standards, comprehensive home solutions available that take into account the use of extended detection of pollutants (indor/outdoor), temperature and air humidity.

The aim of the presented solution was primarily to minimize the costs associated with the implementation and its simplicity. Simple home appliances available on the consumer market, which do not require detailed knowledge and authorization to perform the installation, were taken into account. An important factor was also the availability of literature and description of technological solutions attached to the devices used in the discussed system [3–5].

Comparing the presented solution to those already existing on the market, it can be stated that it is an open solution, enabling easy integration with other smart home systems. This is in contrast to the commercial closed solutions of individual manufacturers. In addition, the scalability of this solution should be emphasized.

3.2. Suspended dust sensors

The basic devices used to control the air purification installation in the apartment are particle sensors PM 1, PM 2.5 and PM 10. The described installation uses an external device in the form of a LookO2 detector located outside the apartment which allows continuous air monitoring (Fig. 2). The data is presented in the form of a light indicator (colour scale) and can be read on the website (Fig. 3).

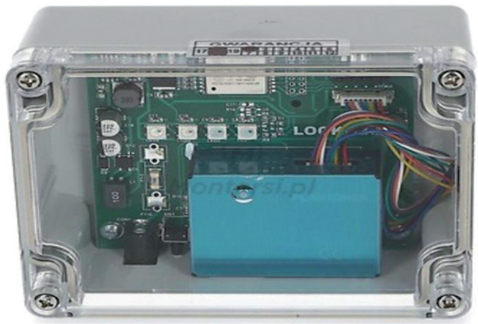

Fig. 2. External air quality detector. Source: own

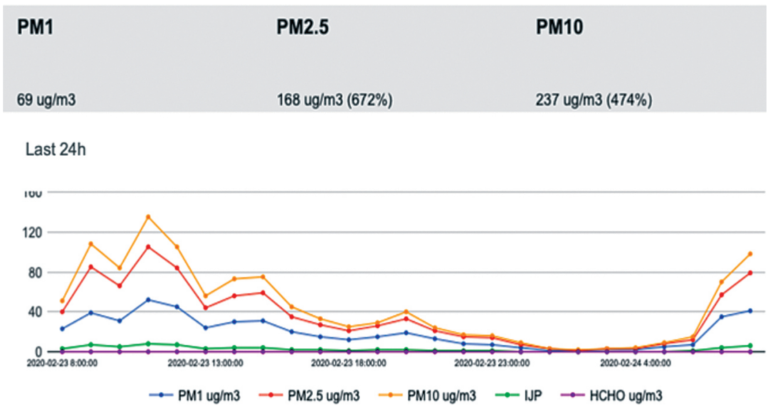

Fig. 3. Average dust concentrations for the last 24 hours. Source: own

This device is used to turn on individual air purifiers located in the apartment after exceeding the set value of PM2.5 dust concentration outside. Internal air quality sensors are used to precisely control the air purifiers in the rooms. During operation, the device monitors the local environment and generates data on pollution in the room. These data are used in home automation. Both presented sensors communicate with the environment using WIFI technology (Fig. 4).

Fig. 4. Appearance of the detector, working device with a temperature and humidity sensor. Source: own

3.3. Temperature and humidity sensor

The second device for automatic air purification in the apartment is a temperature and humidity sensor based on Bluetooth technology. The use of this device allows one to accurately and effectively measure the humidity in the room. This is due to the possibility of placing the device in a convenient place, relatively remote from the source of emission of the purified air, in contrast to the air purifier, which also has a humidity sensor. However, then the sensor is located right next to the emission source, which is the purifier, and the reported results are significantly distorted by the device's operating condition. The presented sensors communicate with the environment using Bluetooth LE 4.2 technology. Software with the MQTT protocol and BLE to WIFI gateways should be used to automate activities such as humidity control with a purifier.

3.4. Bridge Bluetooth – WIFI

The hardware structure of the bridge was based on the Raspberry Pi 0 WH microcomputer (Fig. 5). This device has built-in data transmission components, both in the WIFI standard and in Bluetooth Low Energy 4.2. The unquestionable advantage of such a solution is also the dimensions of the device (the size of the matchbox) and the electricity consumption of 0.7 W.

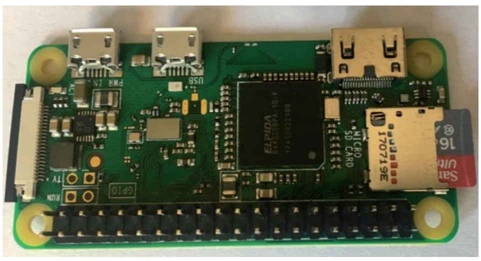

Fig. 5. Devices enabling the installation of software that integrates elements of the heating control installation. Source: own

Standard, free system software is installed in the device, in the form of the Raspbian operating system. In addition, free software was also uploaded, mediating between the automation devices (dust sensors, T/H sensors, air purifiers) [6–8], and control applications available on control devices (smartphones, tablets, computers), in the form of packages:

- Eclipse Mosquitto
- Zewelor / bt-mqtt-gateway
- Nfarina / homebridge
- Arachnetech / homebridge-mqttthing

The apartment uses 3 bridges Bluetooth – WIFI, so that the control devices are within the range of the bridges and a high quality connection is guaranteed.

Having the hardware base with the installed software, the appropriate control software [9, 10] was written for the automation devices.

Example for a single Xiaomi Mi Bluetooth Temperature & Humidity Monitor sensor.

(zewelor / bt-mqtt-gateway software package)

```
mithermometer:
args:
devices:
czujnik_TH5: 4C:65:A8:DE:FE:E8
topic_prefix: misensors
update_interval: 90
```

(nfarina / homebridge, arachnetech / homebridge-mqttthing software package)

```
{
“accessory”: “mqttthing”,
“type”: “temperatureSensor”,
“name”: “Temperatura gabient”,
“url”: “mqtt://localhost”,
“topics”:
{
“getCurrentTemperature”: {
“topic”: “misensors/czujnik_TH5/temperature”,
“apply”: “return JSON.parse(message)”;
},
“getBatteryLevel”: {
“topic”: “misensors/czujnik_TH5/battery”,
“apply”: “return JSON.parse(message)”;
}
},
“integerValue”: true,
“logMqtt”: true
},
{
“accessory”: “mqttthing”,
“type”: “humiditySensor”,
“name”: “Wilgotność gabinet”,
“url”: “mqtt://localhost”,
“topics”:
{
“getCurrentRelativeHumidity”: {
“topic”: “misensors/czujnik_TH5/humidity”,
“apply”: “return JSON.parse(message)”;
},
“getBatteryLevel”: {
“topic”: “misensors/czujnik_TH5/battery”,
“apply”: “return JSON.parse(message)”;
}
},
“logMqtt”: false
},
```

3.5. Air purifiers

There are three air purifiers in the apartment that control the humidity level of the purified air. These devices are of the older type and are not suitable for remote control. The mechanical part of the device in the form of air flirts (HEPA filter, carbon filter) meets the highest standards among this type of purifiers. Therefore, an attempt was made to adapt these devices to the possibility of controlling them by means of an automation system and applications. The task was performed using the Sonoff 4CH DC 5–32 V module (Fig. 6). This module enables remote control of any device with four buttons. You can also choose different modes of operation of the switches (momentary, self-lock, interlock).

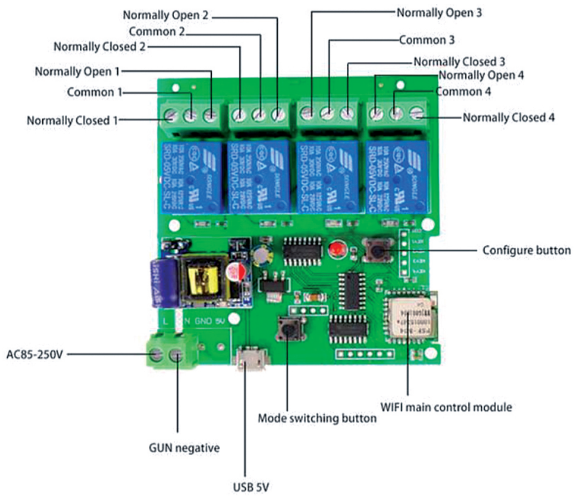

Fig. 6. Switch enabling the installation of software that integrates elements of the air purification control installation. Source: own

In addition, the device has manual switches that can be connected to the existing control panel located on the controlled device via a dedicated socket (Fig. 7).

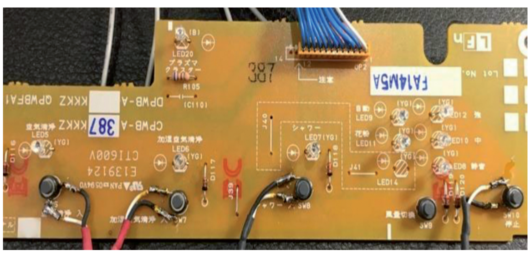

Fig. 7. Connecting the air purifier control board switches to the Sonoff 4CH controller. Source: own

Figure 8 shows the installation of the control module in the SHARP KC 50 air purifier. The controller power supply is integrated with the purifier power supply and the func-

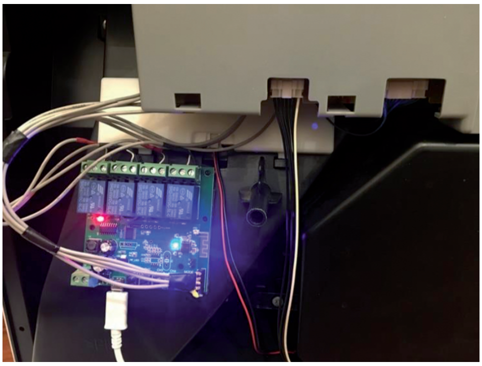

Fig. 8. Installation of the Sonoff 4CH module in an air purifier. Source: own

tionality of controlling four device options is obtained: Clean Air, Clean Air & Humidify, Clean ION Shower, Off Device. The Sonoff 4CH controller has a standard control software related to the manufacturer's application. This solution makes it impossible to integrate the automation controller with devices from other manufacturers, and even more so with applications provided by manufacturers of mobile phones or tablets. The solution to this problem is to upload alternative control software, extending the functionality of the module and enabling full integration with the existing system (Fig. 9). The Tasmota[4] software was used to program the controller.

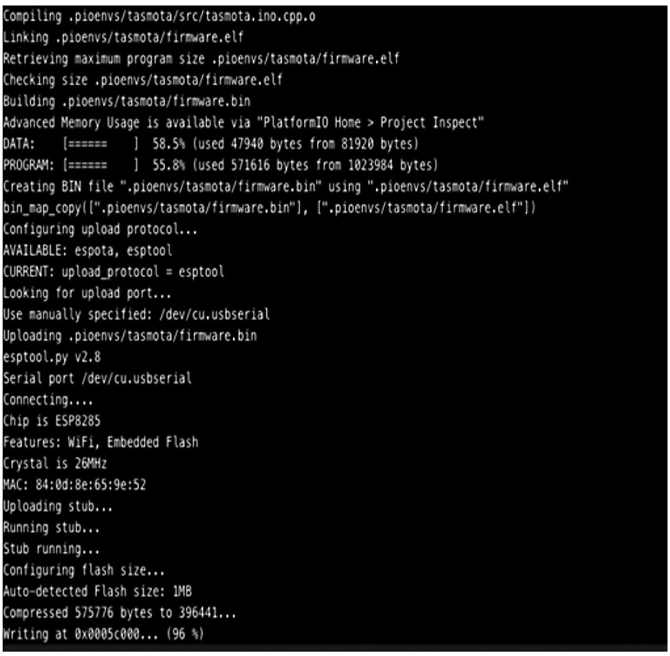

Fig. 9. Uploading alternative software to the Sonoff 4CH controller. Source: own

4. Control aplications

In order to simplify the control of the system as much as possible and provide it with autonomy in making decisions, the goal was to use as few control applications as possible. This software is available for smartphones, tablets and computers. The solution is based on two applications, the basic one provides simple and intuitive control of the system and the additional one allowing to expand the definition of scenarios and scenes depending on e.g., the time of day, the presence of residents at home, etc.

4.1. The home application

The Home application supplied with the device was used for the integrated control of the smart home system (Fig. 10). This application supports multiple smart homes. The user, who owns, for example, an apartment and a holiday home, can with this software control simultaneously both of them. Moreover, thanks to the built-in GPS system, it is possible, depending on the location of the owner (system users), to control events in individual premises. For example, when leaving the apartment, the lighting is turned off and the temperature in the rooms is reduced, while approaching the holiday home, the blinds in the windows are raised and the garage gate is opened. The limitation of the application is the lack of Boolean functions.

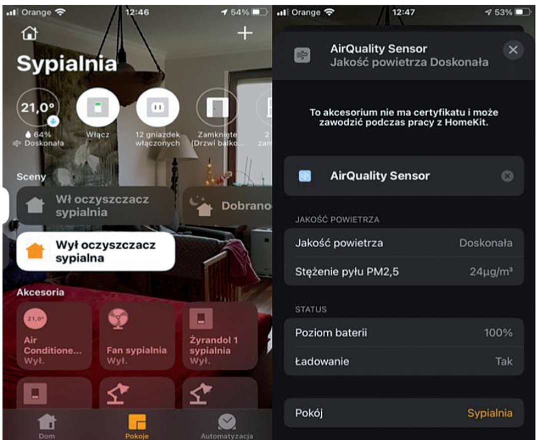

Fig. 10. The appearance of the Home application along with the control and configuration of the head. Source: own

4.2. Home + application

The Home+ application is an extension of the functionality of the Home application, which enables the use of Boolean functions: NOT, AND and NAND, OR and NOR, XOR for automation devices, scenes and automation (Fig. 11). This allows one to program the activation of air purifiers in the apartment depending on the concentration of PM2.5 dust

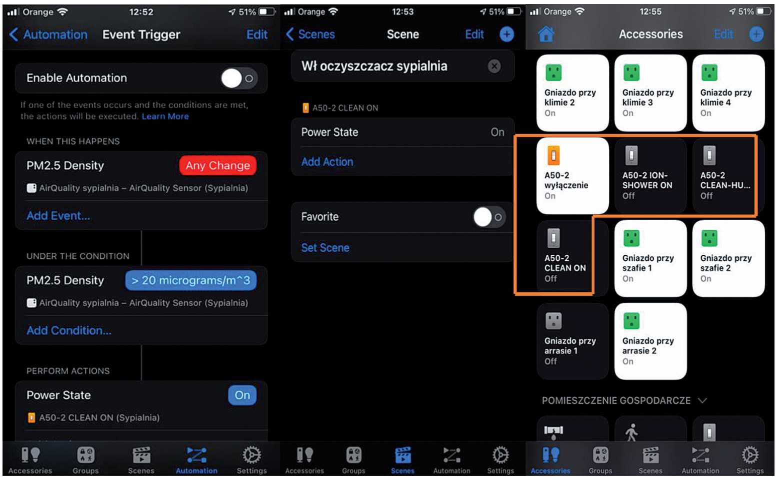

Fig. 11. Appearance of the Home + application defined automations with Boolean functions. Source: own

also depending on additional conditions, e.g., time of day, air humidity in the room, etc. Moreover, it is possible to include additional functionalities in the executive device (air purifier) to control environmental parameters.

4.3. System implementation

In accordance with the presented assumptions of the solution specification, PM 10 and PM 2.5 dust sensors (indoor/outdoor) were used. Air temperature and humidity sensors and three KC series active SHARP purification devices. After the system was triggered, the internal sensors continuously showed the level of air quality defined as “excellent”. Also, the parameters of air humidity, both in summer and winter, oscillated between 45 and 55%, which is an optimal result. During eight months of operation of the system in various air pollution conditions in the vicinity of the described apartment, the efficiency of the purification installation was also checked. After the external and internal sensors indicated that the permissible values of pollutant concentration were exceeded, the system turned on the air purifiers. The operation time of the devices was about 15 minutes from the moment they were turned on until clean air was obtained in the apartment. It can therefore be concluded that the selection of purifier parameters to the size of the apartment is correct and does not cause excessive electricity consumption.

5. Summary

The applied solution for controlling air purification in the apartment, using the Internet of Things technology, primarily provides users with benefits associated to the comfort of environmental parameters in the rooms. The use of time-related scenes guarantees optimal conditions for staying in selected rooms (e.g., PM 2.5 dust concentration, humidity, the generation of a large amount of negative ions in the bedroom for the evening). In addition, automation, which uses scenes of residents leaving the premises and their return, along with appropriate control of purifiers (complete shutdown of devices after the residents leave) allows for a significant reduction in system operating costs. An additional advantage of the system is the ability to operate it both from mobile devices (mobile phone, tablet), computer equipment (desktop computer, notebook) and via a web browser.

6. Conclusions

The described solution presents a procedure for building an air purification system using the Internet of Things (IoT) technology. Using the research results of the study, it will be possible to create an inexpensive, based on commonly available devices, solution improving the air quality in the apartment. Compared to comprehensive and complicated solutions that require professional knowledge in construction, configuration and installation, the approach used enables the widespread use of the proposed solution. Further work related to the air purification system will include the examination of a wider range of devices available on the consumer market and their possibilities of integration with the presented solution. Extending the functionality with the ability to detect adverse events during system operation. Such a factor is, for example, an open window in an apartment, causing an inflow of polluted air. A warning will be generated for the user about the possible disturbed operation of the purifiers.

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Zastosowanie technologii internetu rzeczy (IOT) do sterowania oczyszczaniem powietrza w mieszkaniu

Słowa kluczowe: Internet Rzeczy (IoT), budownictwo mieszkaniowe

Streszczenie:

Utrzymujące się zanieczyszczenia powietrza (SMOG) na obszarze dużych miast w krajach opartych na energetyce i ogrzewaniu węglowym stanowi poważny problem. Poprawa jakości powietrza to obecnie główne wyzwanie metropolii Europy środkowo-wschodniej. Mimo intensywnych działań, średnie roczne stężenie pyłów PM2,5 na tym obszarze przekracza zalecaną przez Światową Organizację Zdrowia normę (zalecana norma – 25 µg). Z danych instytucji zajmujących się ochroną środowiska wynika że np. w Krakowie (Polska) liczba dni ze stężeniami pyłu PM 2.5 przekraczających drastycznie dozwolone normy wynosiła 96 w ostatnim roku. W artykule przedstawiono opis sterowania oczyszczaniem powietrza w mieszkaniu z wykorzystaniem urządzeń automatyki, oprogramowania sterującego oraz aplikacji dostępnych na smartfony, tablety i komputery osobiste. W przedstawionym rozwiązaniu zastosowano technologie posiadające możliwość wykorzystania wolnego (alternatywnego) oprogramowania, rozszerzającego funkcjonalność urządzeń i podnoszące elastyczność systemu sterowania. Za główny cel uznano maksymalizację wygody użytkowników mieszkania oraz możliwie jak największą minimalizację kosztów zużycia energii elektrycznej. Dodatkowo zaadaptowano do potrzeb systemu sterowania oczyszczaniem powietrza istniejące urządzenia w postaci oczyszczaczy powietrza.

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