IoT monitoring system for microclimate parameters in educational institutions using edge devices

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Abstract

Recent years have been defined by the rapid development of information systems, Internet of Things (IoT) technologies, the growth of edge devices, and the development of new sensors for building such systems, which are increasingly being implemented in people's lives, both domestic and social. An essential role in ensuring people's lives is played by the microclimate of the premises where people live, work, and study. As you know, the excess or decrease of the environmental microclimate relative to the norm negatively affects the physiological state of a person, his performance, and concentration and reduces the efficiency of work and training. Therefore, in this work, the problem of round-the-clock monitoring of the microclimate of classrooms is solved by developing an autonomous IoT system using edge devices to measure climatic parameters such as temperature, relative humidity, carbon dioxide level in the air, and the concentration of light air ions with data recording on a smartphone and saving on a remote server. The development is based on the use of IoT technologies, edge devices, and network technologies. The development is part of a system for studying the influence of microclimate parameters on the physiological state of applicants for education. The results obtained in the work will allow development measures to ensure the necessary normal conditions for training in confined spaces.

Keywords

IoT, monitoring system, microclimate parameters, educational institutions, edge devices

1. Introduction

Even though in recent years the provision of educational services has switched to a full or partial online mode, many institutions of higher education, almost all schools, and kindergartens continue to study in classrooms [1, 2]. Therefore, ensuring normal living conditions during classes is an urgent task for the management of educational institutions, which is reflected in the introduction of health-saving technologies in the learning process [3, 4]. One of the factors that can negatively affect the physical condition of applicants for education, the ability

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to effectively perceive information, and concentrate attention, is the provision of normal microclimate conditions in the environment of classrooms [5, 6]. The health and performance of a person are most affected by changes in temperature, relative humidity in the room, the level of oxygen and carbon dioxide in the environment, as well as a significant effect of air purity and its electrical properties, which can be assessed by determining the concentration and polarity of the charge of light air ions. Temperature and humidity can lead to an excessive increase or decrease in body temperature, high blood pressure, changes in heart rate, respiratory rate, etc [5]. An excessive level of carbon dioxide and an insufficient level of light air ions in the air can cause headaches, dizziness, drowsiness, disability, etc [7]. Failure to comply with hygienic requirements for the air regime worsens the perception and assimilation of educational material, and also leads to a deterioration in the health of both students and teachers.

An analysis of materials for monitoring microclimate indicators in educational institutions (and, in principle, most systems for monitoring microclimate parameters) showed that one or two parameters are mainly controlled (usually temperature and humidity), and sometimes atmospheric pressure is also recorded. Thus, the registration of the entire set of parameters recommended by regulatory documents does not occur simultaneously. There is no control at all of such parameters as the concentration of ozone, nitrogen, and air ion composition of the air. Not all devices also monitor the level of carbon dioxide in the air. That is, it does not have universal equipment that would control the change in all microclimate parameters that significantly affect the physiological parameters and well-being of a person.

Recently, the continuous development of technical means and solutions makes it possible to develop microclimate control systems with a wider range, and transfer measured information to cloud servers for storage, analysis, and remote reverse control of these parameters.

At the same time, the unprecedented development of IoT and edge device technologies is taking place, as well as their introduction into many areas of human activity – medicine, transport, housing, communal services, agriculture, energy, ecology, environmental control, etc.

The IoT concept was first formulated back in 1999, and today it is one of the main global trends. Any even old functioning devices can become part of the IoT and perform new functions. Thus, the IoT branch is considered the driver of the fourth industrial revolution [8, 9]. According to Kotelianets [8], Nakonechnyi and Veres [9], IoT is one of the most promising technologies of recent years, which already today creates some new products and leads to the emergence of new IT companies on the market. The world's largest IT companies, in particular, Intel, Google, IBM, etc., have already begun large-scale work in the IoT market and have taken their leading niche in this direction [8, 9].

Therefore, the article **aims** to describe developing an IoT system for monitoring the microclimate parameters in a room with the full necessary set of parameters using an edge device that would allow assessing the impact of their change on the physiological state of a person.

The proposed system is a composite subsystem of the health-saving environment of educational institutions, which contains a subsystem for collecting and analyzing human physiological indicators, a database, includes network technologies, and software.

2. Theoretical background

Mooney [10] considers the influence of microclimate parameters on the well-being of a person in the course of production activities, describes the mechanisms of physical and chemical thermoregulation of the body and determines the optimal and permissible parameters of the microclimate of the working area. Also proposed are methods for normalizing the microclimatic indicators of the production environment to avoid a negative impact on the health of workers.

Zaporozhets et al. [11], Kozlovskaya and Sukach [12] determine the influence of the air ion concentration level on the microclimate indicators of the premises, and analyze the sanitary and hygienic standards of permissible levels of air ionization in the premises. Recommendations are given for improving the standardization of the air ionic composition of the air in working rooms. Theoretical and experimental studies of changes in the concentrations of air ions in working rooms have been carried out. Approaches to modeling temporal and spatial changes in the concentration of air ions in rooms are proposed. The effect of air humidity on changes in the concentration of air ions in industrial premises has been studied. Also, these authors studied the influence of indoor microclimate on people's performance, and the importance of its monitoring in the learning process.

Krawczyk and Dębska [13] considers the influence of temperature, humidity, carbon dioxide concentration, and the illumination of the premises of educational institutions on the productivity of training and the well-being of students held in educational institutions in Poland. Measurements were made using industrial measuring instruments.

Kviesis et al. [14] considers a prototype system for measuring microclimate parameters in the classrooms of the Latvian University of Agriculture, built on the Arduino platform using compatible sensors for measuring air temperature, humidity, and carbon dioxide levels. The architecture of the system is based on the concept of IoT and provides for the transfer of measured parameters to a mobile application for the possibility of remote monitoring of them and receiving warnings about the deviation of the microclimate from the recommended values. The work proved the excess of CO_2, temperature, and humidity above the norm in unventilated rooms.

In Djordjević et al. [15], a software-information model of local and remote aggregation, processing, and visualization of the results of observations of the dynamics of microclimate parameters was developed and implemented based on the concept of the Internet of things.

Sokolova and Bielov [16] presents the principles of building information and intelligent systems for indoor microclimate monitoring; describes the circuitry aspects of building such a system and examples of practical use, and options for remote control of microclimate parameters using IoT technologies.

Al-Dulaimy et al. [17] presents edge computing architecture, considers Characteristics of IoT, edge, fog, and cloud computing, and describes edge computing applications (figure 1). Ashtari [18] also considered the architecture of edge computing and presented it in this form (figure 2).

Other authors cite edge computing reference architecture 3.0. (figure 3) [19] from the core concepts, architecture, key technologies, security, and privacy aspects. The authors concluded that "edge computing provides data storage and computing at the edge of the network, and provides intelligent Internet services nearby, supporting the digital transformation of various industries and meeting the requirements of various industries for data diversification" [19].

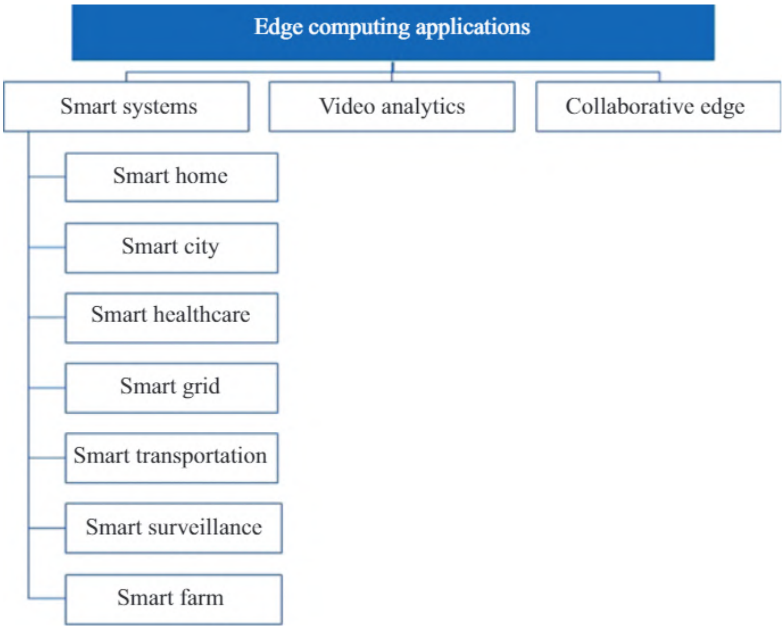

Figure 1: Edge computing applications [17].

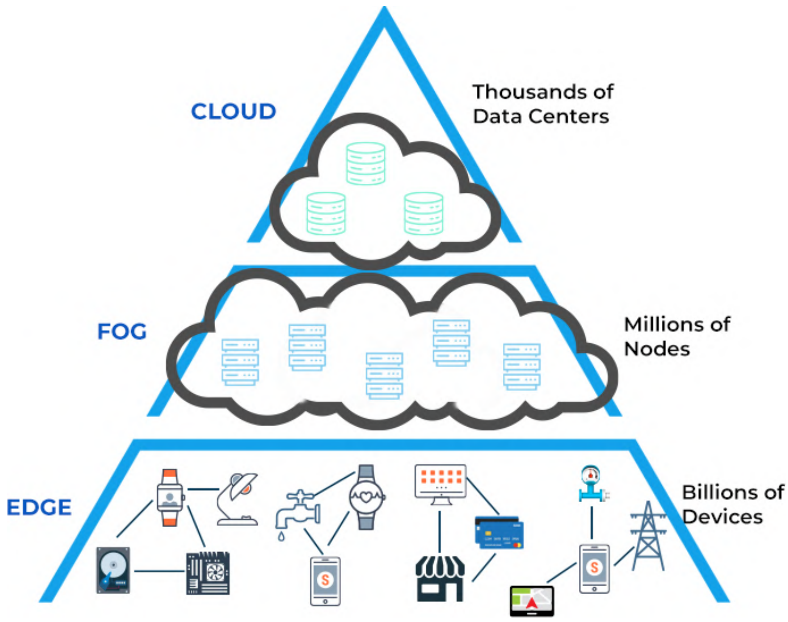

Figure 2: Edge computing architecture [18].

Krishnasamy et al. [20] consider the possibility of using edge computing in medicine and other fields (figure 4). They propose to use the edge device for this through advanced real-time monitoring and analysis of certain data. In particular, in figure 4 demonstrates the development

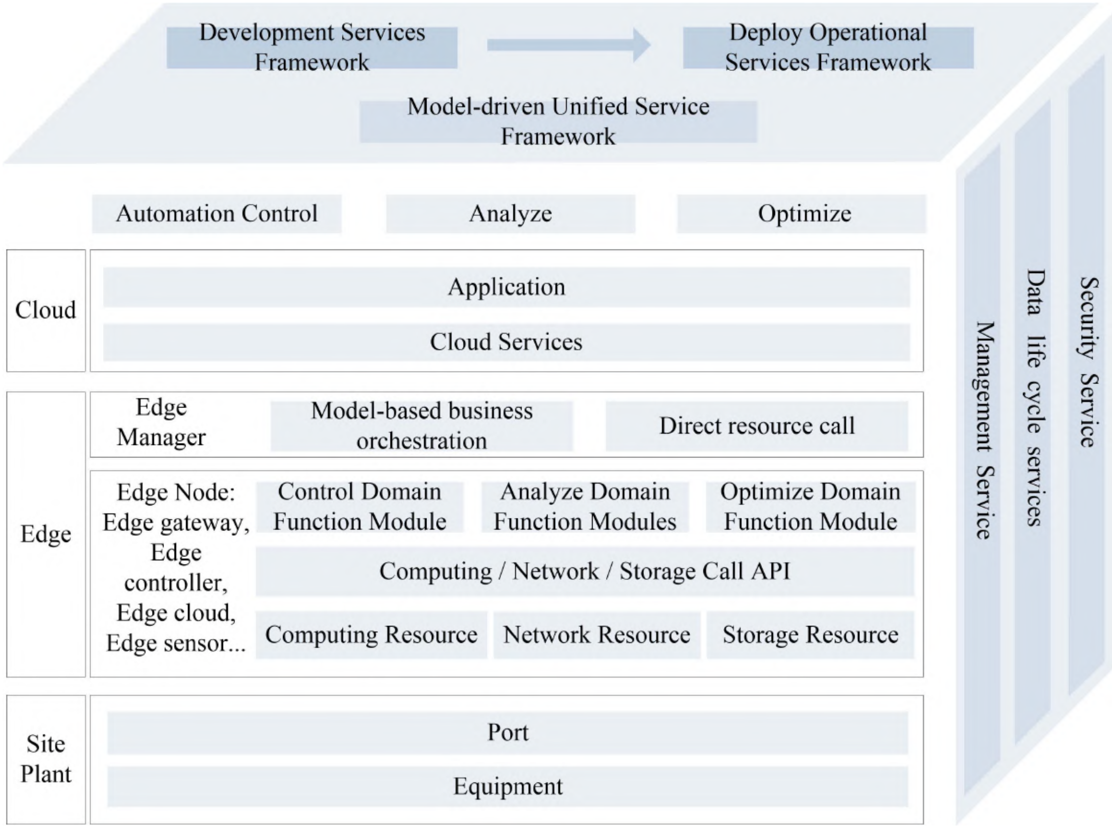

Figure 3: Edge computing reference architecture 3.0 [19].

of digital technologies in healthcare and the use of peripheral computing in healthcare [20].

Also, in the previous works of the authors [21, 22], varieties of edge devices were studied, and their belonging to this species was substantiated.

Certain calculations of the works of these authors became the theoretical and methodological basis for the development of their own IoT system for monitoring indoor microclimate parameters with the maximum required set of parameters using the edge device.

3. Results

Sanitary and hygienic norms for the parameters of the microclimate of the premises of educational institutions are determined depending on the age of the applicants for education, the functional purpose of the premises of the educational institution and are regulated by the following documents:

- sanitary regulations for preschool educational institutions, approved by order of the Ministry of Health of Ukraine dated March 24, 2016 No. 234 [23];
- sanitary regulations for institutions of general secondary education, approved by order of the Ministry of Health of Ukraine dated September 25, 2020 No. 2205 [24];

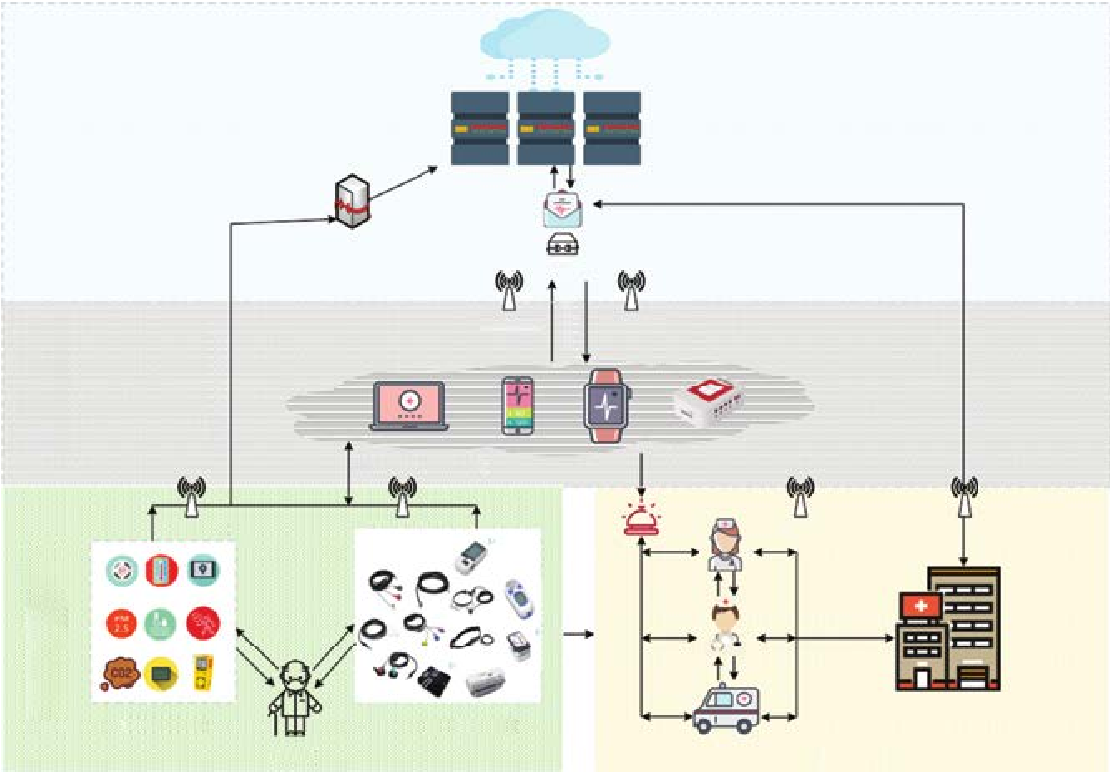

Figure 4: Edge computing in healthcare [20].

- the requirements of the State Sanitary Norms and Rules "Hygienic requirements for the arrangement, maintenance, and regime of special general education schools (boarding schools) for children in need of correction of physical and (or) mental development and educational and rehabilitation centers", approved by order of the Ministry of Health of Ukraine dated 20.02.2013 No. 144 [25].

According to these documents, it is possible to generalize the ranges of normal values of the main indicators of the microclimate on the premises of an educational institution:

- air temperature in classrooms – 18-20 °C;
- air humidity – 40-60%;
- concentration of carbon dioxide – 400-600 g;
- concentration of air ions – 400-600 ion/cm^3.

Let us define the requirements for the design being developed [5]:

- structurally, the monitoring system should contain a block of sensors with a wireless system for transmitting information to the central block for processing and transmitting information, where information from three separate blocks will be received, and the average value of these indicators will be determined, they will be transferred to the central server and the cloud environment, and also displayed on screen in every room. The system will also contain a control unit, a power supply;

- the system should provide measurements and transfer information to the server at certain intervals specified by the program;
- monitor the parameters of the microclimate in the room in real-time;
- it should be possible to expand the functionality of the system by connecting additional sensors, if necessary;
- provides for the provision of an alarm in case of exceeding the established values of the microclimate parameters in the room;
- ensuring autonomous power supply of the system and its energy efficiency;
- the system should be small-sized and cheap to manufacture;
- provides a change of operating modes. In general, the device implements two modes of operation: the first is an active operating mode, the device creates conditions for a comfortable stay of staff and applicants for education, by the standards, the second is an energy saving mode, to increase the measurement range during non-working hours.

Ensure the output of measurement results to a web server, to the chatbot of the Telegram messenger, and remote control of the system operation from these environments.

Taking into account the analysis of the influence of certain indicators of the microclimate on the physiological parameters of applicants for education and employees of educational institutions, a basic set of parameters was formed that need to be controlled, namely:

- air temperature in the room;
- indoor air humidity;
- atmospheric pressure;
- the concentration of carbon dioxide in the air;
- ozone concentration in the room;
- the concentration of air ions.

Classically, four functional levels can be distinguished in the IoT architecture (figure 5). The sensory level is the lowest, containing a set of sensors that receive information about environmental parameters, i.e. providing collection and processing of information in real-time. And causes the integration of these devices into the measuring system. At the network level, the means and devices of the network infrastructure are considered, which ensures the integration of heterogeneous networks into a single platform. The service level contains a certain set of services designed to store information, create databases, automate certain processes, process data, etc. The fourth level of the IoT architecture includes applications for displaying and managing information, as well as the ability to reverse control climate control devices [26].

An important issue in building a monitoring system for microclimate parameters is the organization of information transfer at the local level. The use of radio communication (WLAN, Wi-Fi, WiMAX networks) in computer networks has opened up new prospects for the use of radio communication [8] for receiving and transmitting information from various sources. Today, the organization of a network that can link sensors, routers, servers, and other communication

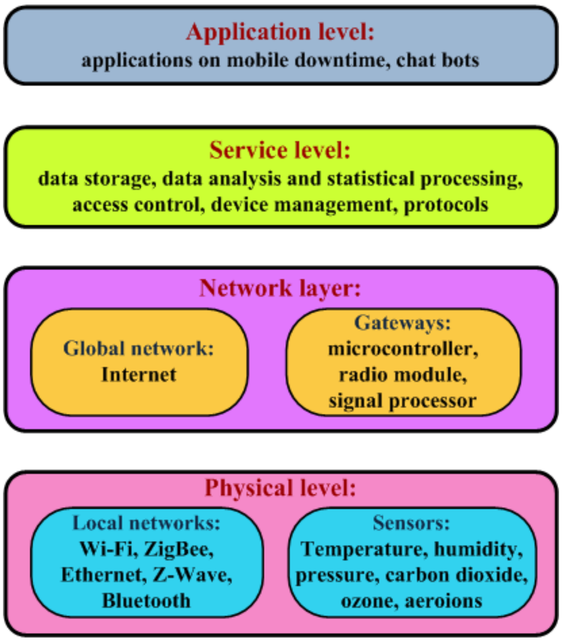

Figure 5: Architectural construction of the microclimate monitoring system based on IoT.

nodes has transformed into the so-called wireless sensor networks – WSN (Wireless Sensors Network) [8].

In a general sense, WSN is a set of small reading devices capable of registering changes in various environmental parameters and broadcasting these parameters to other similar devices within reach for a specific purpose, for example, video surveillance, environmental monitoring, etc., including hardware and software architecture, network technologies and connections, distributed algorithms, software models, data management, security, etc. In general, each such device must be equipped with a microcontroller, a transceiver, a battery, and a set of sensors to measure certain environmental parameters [8, 9]. Intelligent nodes of such a network are capable of relaying messages from each other in turn, providing a significant system coverage area with low transmitter power. This results in the highest energy efficiency of the system.

The IEEE 802.15.4 standard for building a WSN is generally accepted, which defines, in addition to the physical layer (Wireless Personal Area Networks, WPAN), also a part of the link layer – the medium access control layer (MAC) [8]. The most promising for building a WSN is the use of broadband technologies included in the latest edition of the IEEE 802.15.4 standard since they allow you to create transceivers with low power consumption. The basic signal transmission distance for IEEE 802.15.4 is 10 meters, which is quite enough for WSN. The maximum data rate is 250 kbps. The main functions of such systems are safety and optimal use of energy resources.

Possible options for the architectural construction of a system for monitoring the parameters of the microclimate in a room with different technologies for transmitting information are shown in figure 6.

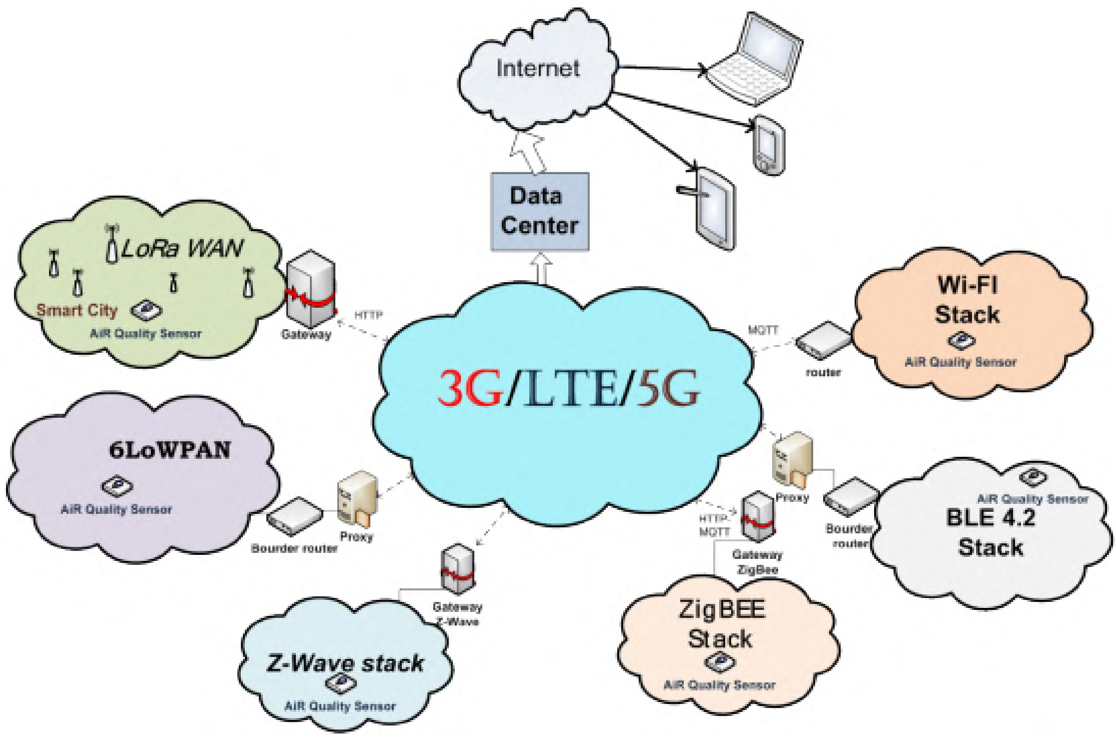

Figure 6: Options for the architectural construction of the IoT network of the indoor climate control system with the maximum required set of parameters using the edge device [9].

Figure 7 shows a block diagram of the developed system for monitoring indoor microclimate parameters [5], taking into account the above requirements and features of building such systems.

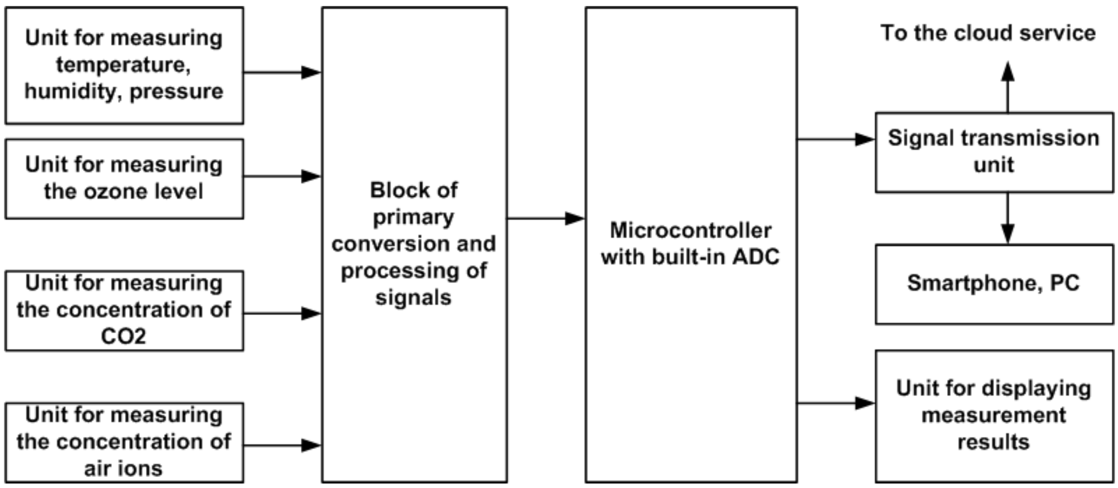

Figure 7: Scheme of the microclimate monitoring system of educational classrooms

To implement the sensory level, the following sensors were used: the BME680 air quality sensor module, which is designed to measure temperature, air humidity, and atmospheric pressure, as well as assess air quality with the corresponding indication; an MH-Z19B carbon dioxide sensor, an MQ-131 ozone sensor, and a sensor for measuring the concentration of light air ions developed by the author [5].

As a microcontroller for collecting, processing information, and control, ESP8266 boards were used, containing built-in transceivers with a Wi-Fi interface and inexpensive, small-sized, and energy-saving.

The advantage of using and implementing such an architecture is that it is possible to use the collection of information at distances greater than directly at the computer itself, without losing data transfer speed. In addition, the data transmission channel is protected, which satisfies the requirements of reliability and authorized access to the microclimate control system.

At this stage of the study, the work of the assembled layout of the monitoring system for microclimate parameters is being tested. The output of the measurement results is implemented on the display in the room and displayed in the Telegram chat.

A chatbot is an artificial intelligence program [27] that simulates an interactive conversation between a person and IoT things using a key, pre-calculated text signals. The Telegram user and the sensor microcontroller program take part in the communication.

The user can interact with the bot using the messenger interface elements: send messages, press buttons, and set commands using the online mode.

The system works according to a fairly simple algorithm. Management is carried out through Telegram chatbot. That is, when a command is sent, the system reads it and executes the function of this command. For example, when sending a command to analyze the characteristics of a room, they are displayed as a message in the chatbot.

Figure 8 shows the algorithm of the remote climate control system in classrooms. After starting the system, the microcontroller sends a request to connect to the Wi-Fi network. After that, the system is ready to send messages to Telegram chatbot.

After connecting to the network, the system begins to interrogate the outputs of the sensors and check the specified limits for the parameters that should be in the room. If the parameters are normal, then the system starts all over again, if the parameters go beyond the limits, the system will turn on the necessary devices to return these parameters to normal.

Also, the system provides for changing parameters using commands. To display parameters in the messenger, you must enter the `/check_sensors` command. When the `/operationg_mode` command is entered, the system sets the boundaries that transfer the device to the operating mode, that is, to the mode in which classes are conducted. When you enter the `/low_energy_mode` command, the system enters the energy-saving mode, that is, the idle mode.

The microcontroller program was written in the Arduino IDE development environment. To work with the Telegram chatbot, the UniversalTelegramBot library was used, which implements all the necessary functions. This library is simple, but it is quite enough for this project.

Figures 9, and 10 show screenshots of the results of the chatbot.

The results of the chatbot's response to changes in indicators above the norm are shown in figure 11 (in the system layout, the light indicator turns on).

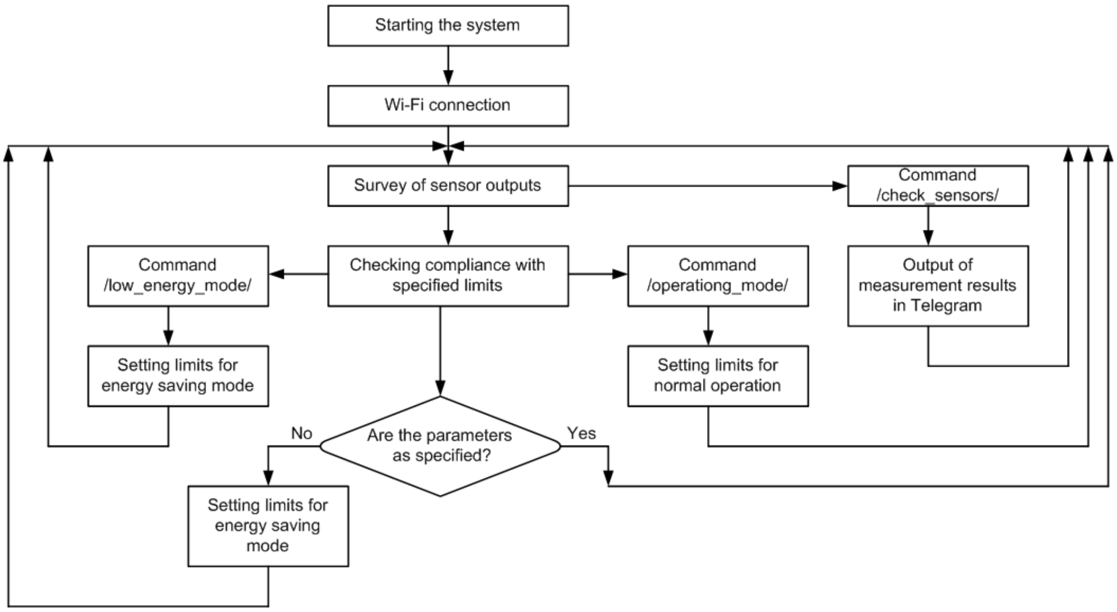

Figure 8: Algorithm of the microclimate monitoring system in educational classrooms.

With the help of the developed system, a series of measurements of the state of the microclimate in the classrooms in the classroom of students was carried out, the results of which are presented in table 1.

Table 1
The results of measuring the parameters of the microclimate in the classrooms.

Measurement time, hour	8.50	9.00	9.10	9.20	9.30	9.40	9.50	10.00
Temperature t, °C	23.29	23.25	23.23	24.03	24.08	24.10	24.12	24.33
Humidity, ψ, %	20.33	20.38	20.39	20.47	20.70	20.53	20.32	20.63
The concentration of air ions, ion/cm^3	436	452	420	373	415	320	250	282
CO_2 concentration, ppm	180	185	232	250	256	280	284	312

4. Conclusions

This study describes the architecture and principles of building the indoor microclimate parameters control system developed by IoT with the maximum necessary set of parameters using the edge device, the technical measurement unit of which is located in the classrooms, the measurement results are displayed on the device screen and transmitted to the server and cloud environment. Measurement data, at the request of the client, can be displayed in the chatbot of the telegram messenger. Through this chatbot, you can implement reverse control of microclimate parameters and set the operating modes of the monitoring system.

The microclimate remote monitoring system is implemented by the concept of the Internet of

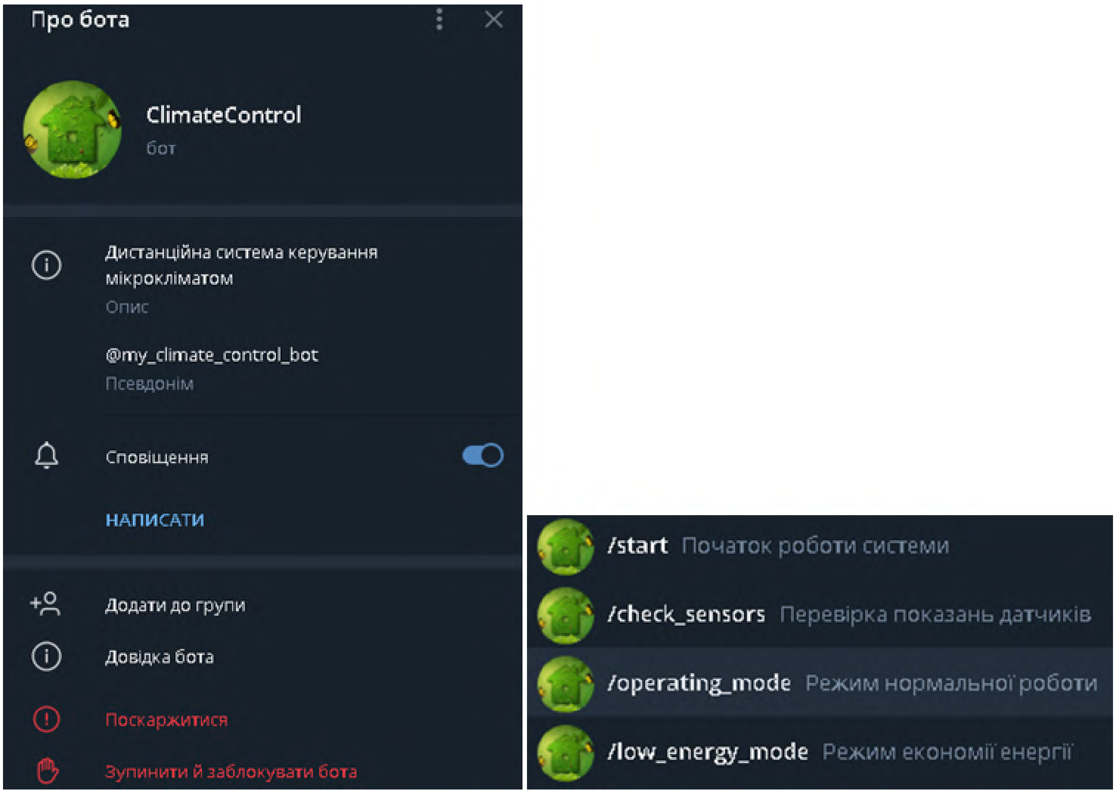

Figure 9: Chatbot "ClimateControl" and its menu.

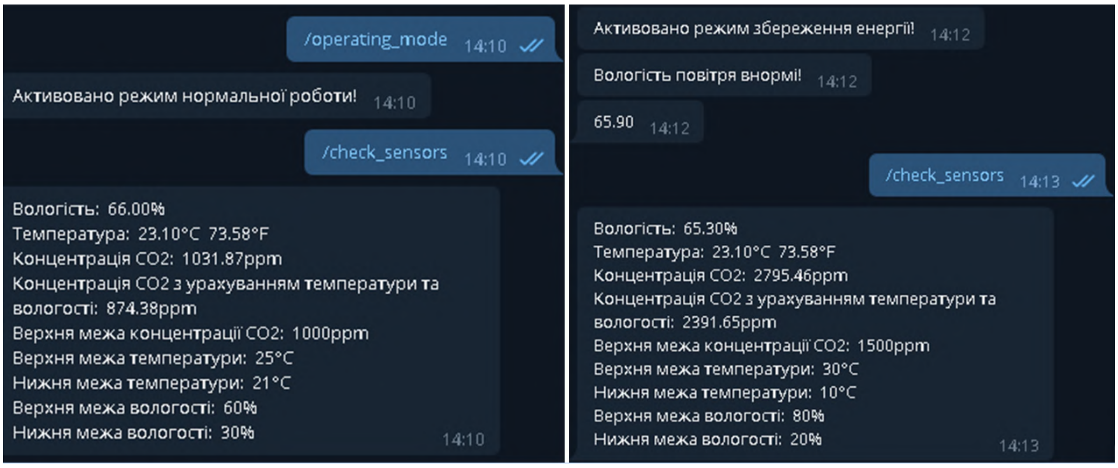

Figure 10: Checking the readings for the operating mode and the energy-saving mode.

Things (IoT) and using an edge device. The main idea of the concept is the connection of sensors and actuators using a radio channel. Moreover, the coverage area of such a network can range from several meters to several kilometers due to the ability to relay messages from one element

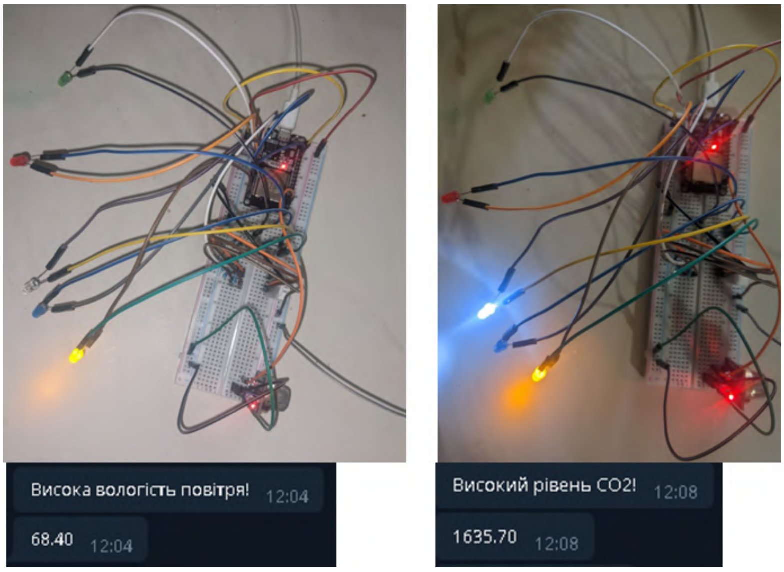

Figure 11: Light and sound alarm in the chatbot for exceeding the microclimate parameters.

to another. Wireless recorders provide the flexibility you need to add and/or move monitoring points, as well as ease of use and removal of devices for calibration and maintenance. The data logger's independent power supply ensures that data is retained in the event of a power outage.

In the future, a web server will be developed to access the database of measured indicators. Measurement and saving of results are carried out in real-time.

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