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A system for monitoring the microclimate parameters of premises based on the Internet of Things and edge devices

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Abstract. Recent years have been characterized by the rapid development of Internet of Things (IoT) and edge device technologies. Systems of various purposes with IoT elements and edge devices are increasingly finding practical use in people's lives, the IoT element base is expanding and improving, which makes it possible to develop effective measuring systems, including those with feedback control. 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 principles of building microclimate monitoring systems are presented, the requirements for the system are set, the criteria for choosing the elemental base and the technical characteristics of each component are given. The structure of the air ion concentration sensor developed by the author and the method of measuring the air ion concentration in the room are also described. The structural diagram of the developed microclimate parameters monitoring system is also presented. 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. Research conducted using the developed system will allow better formation of student learning conditions in order to achieve maximum performance indicators.

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 [6, 8]. Therefore, ensuring normal living conditions during

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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, 7]. One of the factors that can negatively affect the physical condition of applicants for education, the ability to effectively perceive information, and concentrate attention, is the provision of normal microclimate conditions in the environment of classrooms [10, 28]. 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 [10]. An excessive level of carbon dioxide and an insufficient level of light air ions in the air can cause headaches, dizziness, drowsiness, disability, etc [20]. 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 [12, 22]. According to Kotelianets [12], Nakonechnyi and Veres [22], 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 [12, 22].

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.

The novelty of the contribution is the application of the edge device in the development of a system for monitoring the parameters of the microclimate of educational premises with data transmission via the Internet and the use of this system to determine the impact of changes in the microclimate on the condition of students, on their perception of information for the purpose of developing a health-preserving environment of the university.

2. Theoretical background

Mooney [21] 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.

Kozlovskaya and Sukach [13], Zaporozhets, Hlyva and Sidorov [30] 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 [14] 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, Klavina and Vitols [16] 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. [5], 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 [29] 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. [1] presents edge computing architecture, considers Characteristics of IoT, edge, fog, and cloud computing, and describes edge computing applications (figure 1). Ashtari

[2] 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) [4] from the core concepts, architecture, key technologies, security, and privacy aspects. The authors concluded

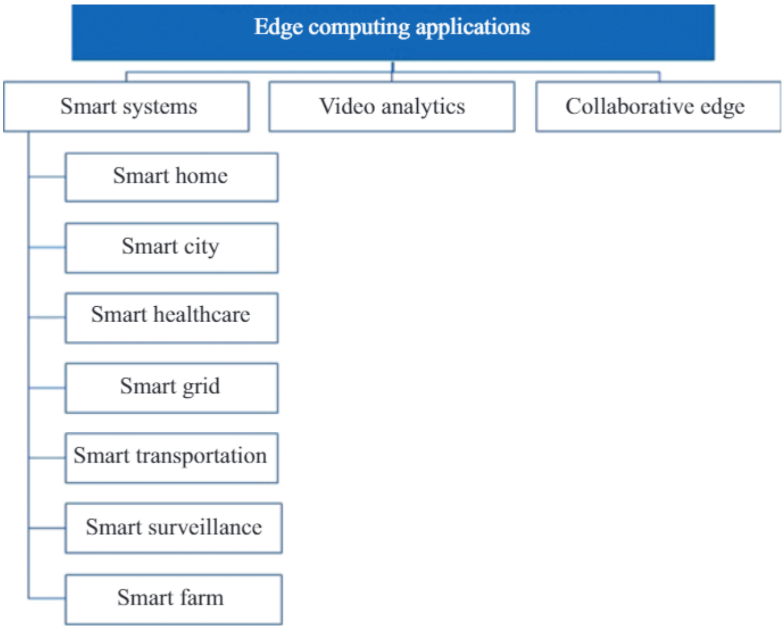


Figure 1: Edge computing applications [1].

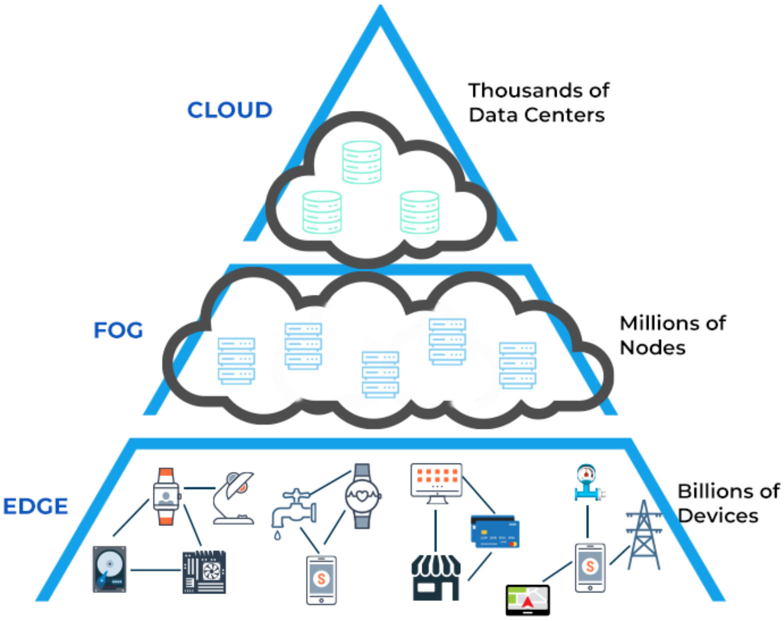


Figure 2: Edge computing architecture [2].

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” [4].

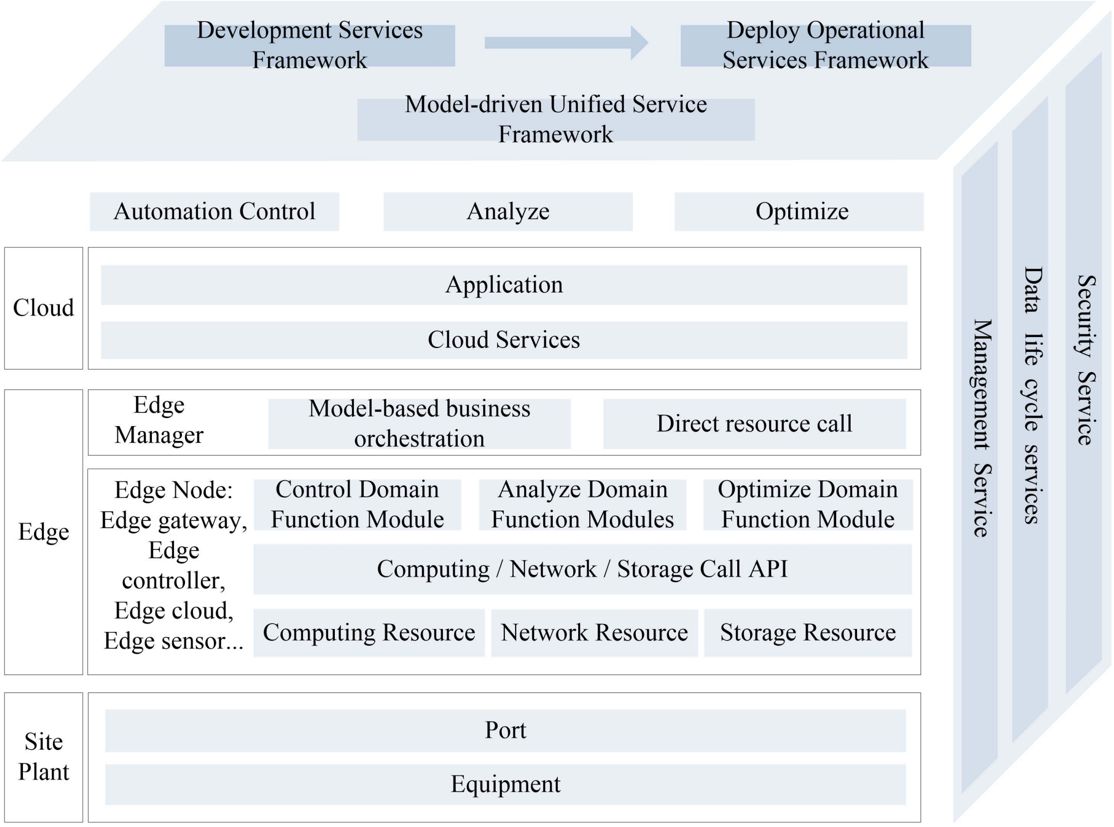


Figure 3: Edge computing reference architecture 3.0 [4].

Krishnasamy, Varrette and Mucciardi [15] 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 of digital technologies in healthcare and the use of peripheral computing in healthcare [15].

Also, in the previous works of the authors [23, 25], 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.

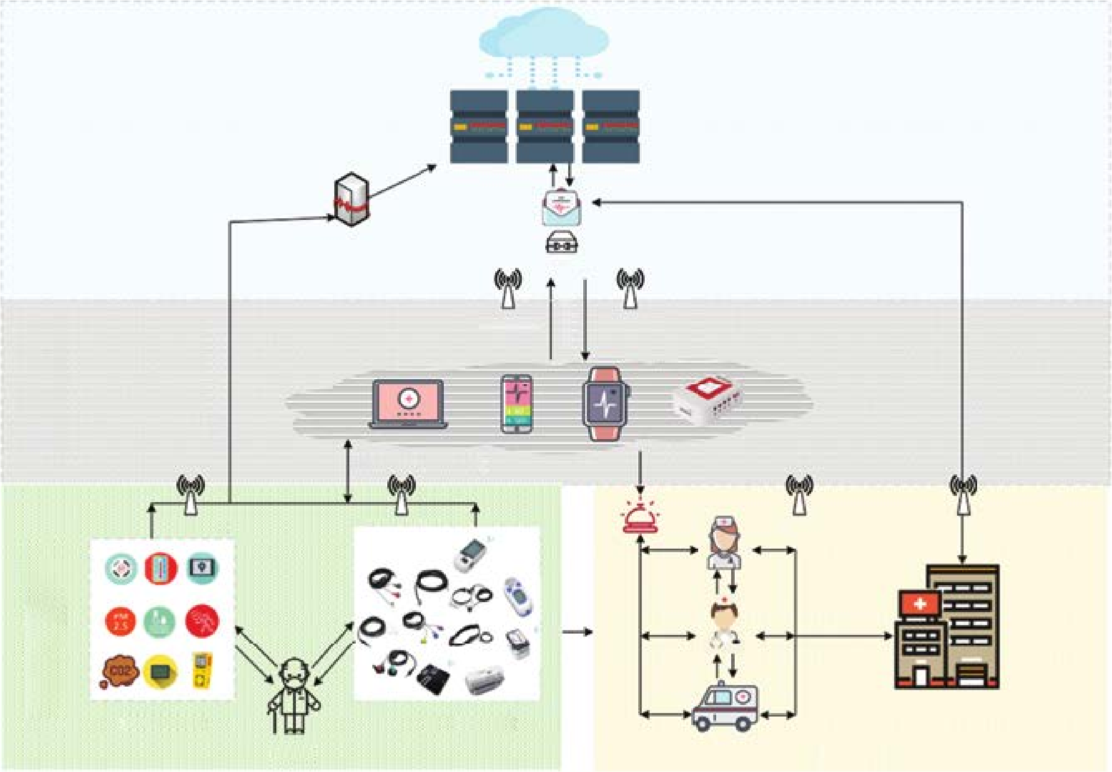


Figure 4: Edge computing in healthcare [15].

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 [18];
- sanitary regulations for institutions of general secondary education, approved by order of the Ministry of Health of Ukraine dated September 25, 2020 No. 2205 [19];
- 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 February 20, 2013 No. 144 [17].

3.1. Requirements for the system being developed

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 [10]:

- 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.

Let's consider the main components of the indoor microclimate monitoring system from the standpoint of the building according to the IoT concept, which must be developed, thought through, and selected:

- sensors (smart sensors): information capture sensors, embedded systems, real-time operating systems, uninterruptible power supplies;
- sensor communication system: the coverage area of wireless personal networks is from 0 sm to 100 m. Low-speed, low-power information channels are used for data exchange between sensors, which are often not built on the IP protocol;
- local computer network (LAN): usually these are data exchange systems based on the IP protocol, for example, 802.11 Wi-Fi networks for fast radio communication;
- routers, gateways, edge devices: this includes various means and devices used for communication between things, the Internet, and cloud services;
- global computing network: operators of cellular or satellite communications, operators of low-power global networks. Commonly used Internet transport protocols for IoT and network devices (MQTT, CoAP, and even HTTP);
- clouds: various cloud providers and their services;
- data analysis services: specialized applications that allow the processing of huge amounts of information that are transferred to the cloud;
- security: when combining all the elements of the architecture, issues of cyber security arise. Security concerns every component: from sensors of physical quantities to digital hardware, radio communication systems, and data transmission protocols themselves. Security, reliability, and integrity must be ensured at every level.

3.2. Development of a microclimate monitoring system

Sensors together with the entire infrastructure for integration with the level of event processing via the Internet from the so-called edge area of figure 5.

Data coming from the boundary area is stored and processed according to the tasks (level of event processing and analytics, event processing, Platform). At this level, data is stored (storage), processed (Event Processing), and forwarded to the required applications (Real-Time Message

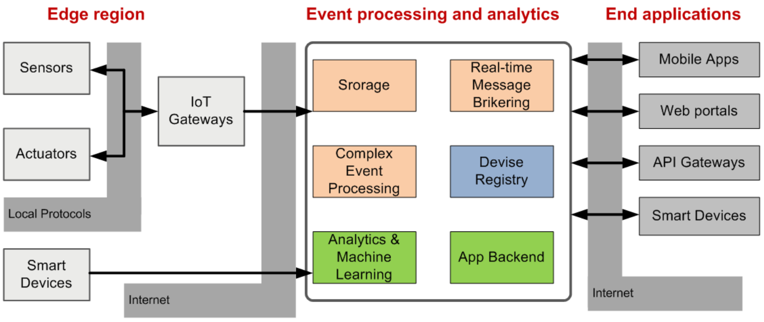


Figure 5: An example of the architecture of the Internet of Things system.

Brokering, Stream Processing). In addition, at this level, administration and management of devices from the edge area (Device Registry, Edge Device Management) take place. Events (data) are processed using analytical services (Analytics), based on which machine learning (Machine Learning) is carried out, which allows you to draw certain conclusions about the object. This level is usually implemented using cloud or fog computing.

Obtaining results, control, remote control, and administration of the system is carried out through end applications using the Internet.

Classically, four functional levels can be distinguished in the IoT architecture (figure 6). 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].

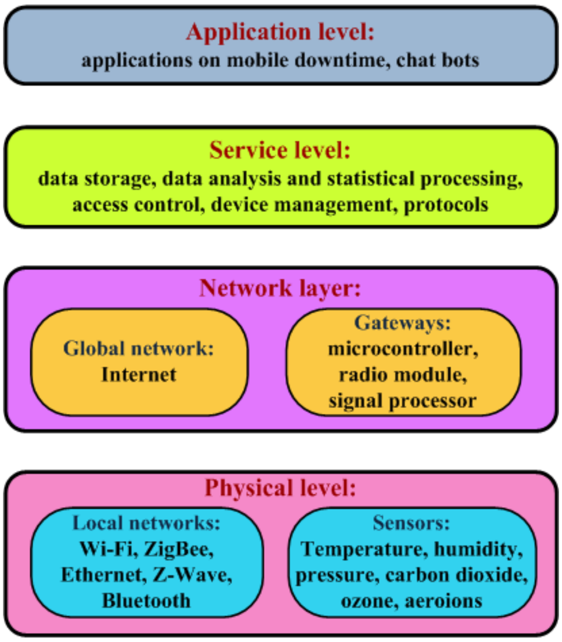


Figure 6: Architectural construction of the microclimate monitoring system based on IoT.

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 [12] for receiving and transmitting information from various sources. Today, the organization of a network that can link sensors, routers, servers, and other communication nodes has transformed into the so-called wireless sensor networks – WSN (Wireless Sensors

Table 1
Comparative characteristics of wireless data transmission technologies.

Technology	ZigBee	BLE	Wi-Fi
Frequency, MHz	868, 915, 2400	2400-2483	2483-5500
Transmission speed, Kbit/s	20, 40, 250	1000	100- 54000
The number of nodes	1 router serves up to 32 nodes	1 router serves up to 7 nodes	Min 2 nodes
The radius of action, m	10-100	50	150
Capacity	250 Kbit/s	3 Mbit/s	300 Mbit/s
Battery life, h	2400-2400012	24-240	-120
The maximum number of network elements	65536	7	100

Network) [12].

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 [12, 22]. 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) [12]. 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 7.

Table 1 shows the comparative characteristics of the main data transmission technologies.

To transfer data from sensors to the Internet space, two technologies are necessary: a router gateway and basic Internet protocols that ensure the efficiency of data exchange. Edge routers manage and monitor the state of the respective mesh networks, as well as level and maintain data quality. The router plays an important role in creating virtual private networks, virtual local networks, and software-defined wide-area networks. They can contain thousands of nodes served by a single edge router, and to some extent, the router serves as an extension to the cloud (edge device). At this level, several protocols are used, necessary for data exchange between nodes, routers, and cloud services within the IoT system.

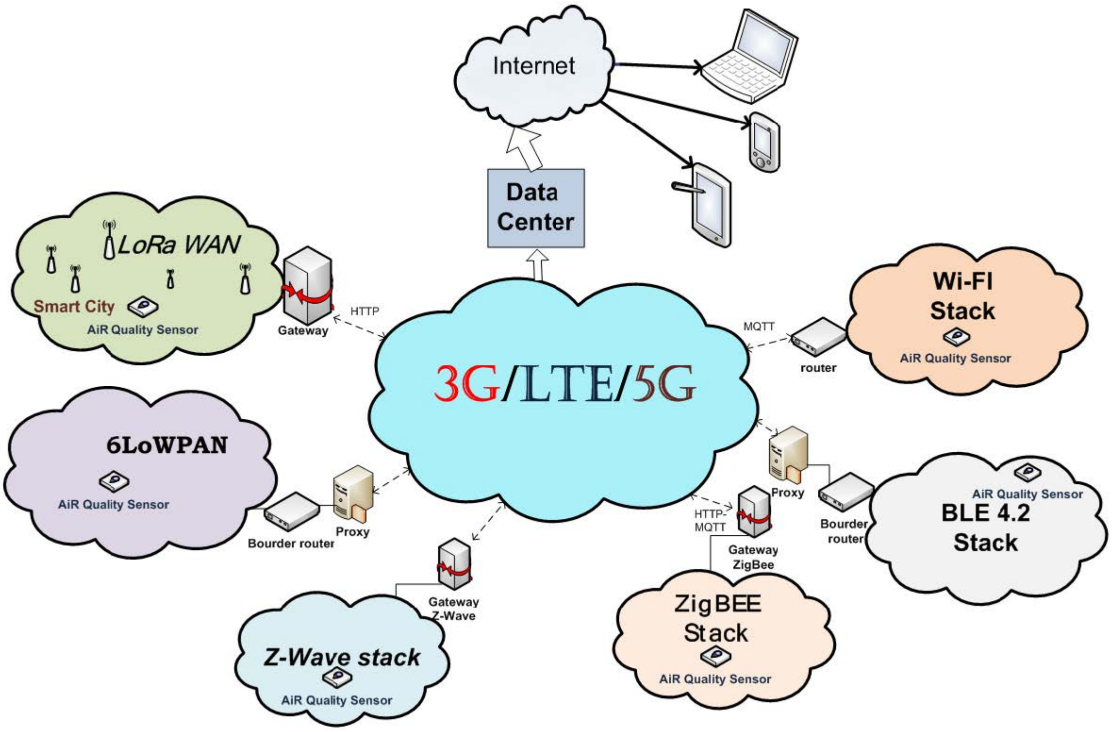


Figure 7: Options for the architectural construction of the IoT network of the indoor climate control system with the maximum required set of parameters using the edge device [12].

IoT data transmission requires efficient, energy-saving, low-latency protocols that can easily and securely send data to and from the cloud. From the existing protocols, we chose MQTT – a protocol for collecting data from devices and transferring them to servers [5]. It is an asynchronous simple protocol with several control options used in real-time, so the response time is usually set in seconds and does not exceed one second.

The principle of operation of the protocol is based on the packet data transmission of the GPRS (General Packet Radio Service) system. Unlike the GSM signal, when transmitting information via GPRS, a separate line is not allocated, the data is transmitted in portions. Thanks to this, simultaneous data transfer is possible, and the speed can reach up to 171.2 kbit/s.

The stages of data transmission by the MQTT protocol are presented in figure 8.

The main difference between the operation of this protocol and the protocols included in the IP protocol stack is that the exchange of messages does not take place directly from the translator to the client (receiver) but through a so-called server (broker). There is the following client-broker scheme (publish/subscribe). Clients connect to a broker, which acts as an intermediary in the exchange of data between them. Several clients inform the broker about the subject of the request. When another client posts a message in this thread, the broker forwards the message to all subscribing clients. So, requests between clients are transited through a server (broker).

MQTT works at the application layer on top of the TCP protocol (figure 9), which provides a simple level of reliability.

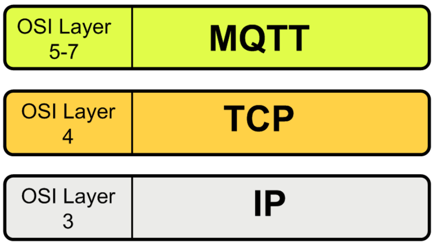


Figure 8: Stages of data transmission by the MQTT protocol.

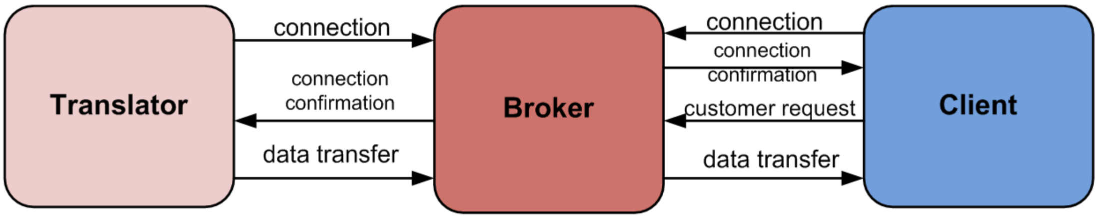


Figure 9: Presentation of the MQTT protocol at the application level.

Every byte entering the communication channel must be delivered to the recipient, even if multiple attempts are required. This is implemented simply and most often without problems, but it does not allow you to control synchronization. In the case of a slow subscriber, single-channel TCP traffic is duplicated. Due to constant communication with the server, MQTT can process large data sets. Unlike other protocols used for M2M, MQTT can not only receive and process data from cloud environments, but also transmit information back to the device.

Figure 10 shows a block diagram of the developed system for monitoring indoor microclimate parameters [10], taking into account the above requirements and features of building such systems.

The following sensors were used to implement the sensor level (figure 11): BME680 air quality sensor module, MH-Z19B carbon dioxide, and MQ-131 ozone sensors, a sensor for measuring the concentration of light aeroions developed by the author [9].

The BME680 sensor is a module for measuring air quality parameters, designed for measuring temperature, air humidity, and atmospheric pressure, as well as air quality assessment with a corresponding indication based on the built-in data processing algorithm. The module works in two data output modes: continuous output and on-demand output, which can adapt to different operating conditions.

Technical characteristics of the BME680 module:

- Temperature measurement range: from -40°C to +85°C.
- Humidity measurement range: from 0% to 100%.
- IAQ measurement range: 0 to 500.
- Air pressure measurement range: from 300 to 1100 hPa.
- Frequency of measurements: by default 3 sec.

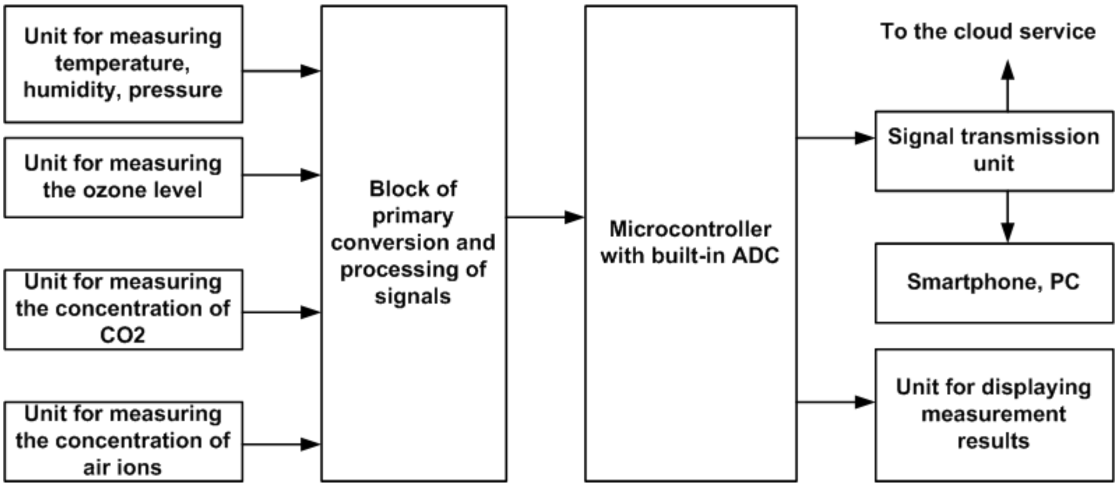


Figure 10: Scheme of the microclimate monitoring system of educational classrooms [11].

BME680 MH-Z19B MQ-131

Figure 11: Element base used in system development.

- Operating voltage: 5 V.
- Average current consumption: 12 mA.
- Operating temperature: from -40°C to +85°C.
- Storage temperature: from -40°C to +125°C.
- Size: 12 x 30 mm.

The MH-Z19B sensor is designed to measure the level of carbon dioxide and has two output interfaces, temperature compensation, high linearity, and low power consumption.

Technical characteristics of the MH-Z19B sensor:

- Measured gas: CO_2.
- Operating voltage: from 3.6 to 5.5 V.
- Logic level voltage: 3.3 V.
- Average current consumption: < 18 mA.

- Level of logical signals: 3.3 V.
- Measured range: from 0 to 0.5%.
- Output signals: UART, PWM.
- Warm-up time: 3 minutes.
- Measurement time: T90 < 60 s.
- Operating temperature: from 0 to 50.
- Operating humidity: 0 to 95% RH.
- Dimensions: 33 mm × 20 mm × 9 mm.
- Weight: 21 grams.

The MQ-131 sensor module is designed to determine the concentration of ozone in the air. Technical characteristics of the MQ-131:

- Sensor type: Semiconductor.
- Detectable gas: Ozone (O_3).
- Gas concentration: 10-1000 ppm.
- Supply voltage: 5 V.
- Power consumption: 900 mW.
- Sensor resistance: 50 kΩ – 500 kΩ (at 50 ppm O_3).

To measure the concentration of aeroions, it is proposed to use the "open collector" method improved by the author, which consists in measuring the charge created in space by aeroions of a certain sign [9]. The charge generated in space by air ions is induced on the surface of the conductor, which is located in the measurement zone and is the receiving electrode, and flows from it to the storage capacity connected in series with the receiving electrode. The amount of induced charge depends on the size and shape of the receiving electrode and is not determined by the parameters of the electrostatic field. Next, the accumulated charge is measured by a current integrator, which allows you to measure the charge directly, and not the ion current.

Aeroion concentration n can be determined from the ratio through the recorded current

$$n = \frac{i}{eS}, \tag{1}$$

where S is the screen area; e is the charge of the electron, and is the recorded current created by the total charge of aeroions in space.

Or due to the charge of aeroions

$$n = \frac{Q}{e \cdot S \cdot t}, n = \frac{Q}{e \cdot V \cdot t} \tag{2}$$

where Q is the charge induced on the receiving electrode in μC; V is the volume of the receiving electrode, in cm^3; e – electron charge; n – concentration of air ions; t is the measurement time.

The volume V of the volumetric receiving electrode is selected from the condition that $N = 1/e \cdot V = 1; 2; 5 \times 10k$ 1/cm^3, where $k = 0; \pm 1, \pm 2, ...$ In this case, the calculation of the concentration of aeroion charges N is carried out directly in scale units according to the measurement range.

The use of the "open collector" method for measuring the concentration of air ions simplifies the measurement system, and the location of the measuring electrode in an open space makes it possible to take into account external fields and convective flows and allows measurements to be made at any point in space, even near a biological object.

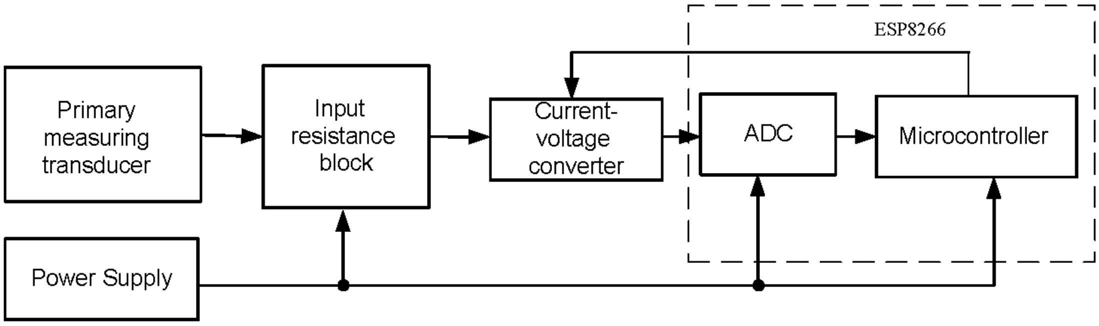


Figure 12: Structural diagram of the air ion measurement unit [9].

The air ion counter works as follows: the charge of the point of space where it is placed is applied to the receiving electrode of the PVP, and at the moment of connecting the storage tank, it all flows to it. Next, the signal is sent to the current-voltage converter, which is converted into a digital code using the ADC. Resetting the measurement parameters and data transfer is done using the ESP8266 module.

ESP8266 boards are used as a microcontroller for information collection, processing, and control, which contain built-in transceivers with a Wi-Fi interface and are inexpensive, small-sized, and energy-efficient.

The ESP8266 chip is a Wi-Fi module that can be used as a Wi-Fi adapter, transmitting data via SPI, SDIO, I2C, or UART interfaces. ESP8266 contains an antenna switch, a matching transformer, a power amplifier, a low-noise amplifier, filters, and power management modules. Compact design and a high degree of integration allow you to minimize the size of the printed circuit board and the number of external components. The ESP8266 contains an enhanced version of the 32-bit processor and integrated random access memory (SRAM).

Technical characteristics of ESP8266:

- standard WiFi 802.11 b / g / n;
- built-in stack of TCP / IP protocols;
- built-in 32-bit MCU with low power consumption;
- built-in 10-bit ADC;
- RF switch;
- RF resistance transformer;
- LNA;
- power amplifier;
- built-in PLL and power control units;
- Wi-Fi 2.4 GHz;
- WPA / WPA2 support;

- SDIO 2.0, (H) SPI, UART, I2C, I2S, IRDA, PWM, GPIO, STBC, 1x1 MIMO, 2x1 MIMO;
- consumption up to 215 mA in transmission mode, 100 mA in reception mode, 70 mA in standby mode, and consumption in deep sleep mode.

In addition to the microcontroller itself, there are many options for integrating it into development boards, including the NodeMCU ESP8266. NodeMCU is an open-source Lua-based firmware and development board specifically designed for IoT applications. It includes firmware that runs on Espressif Systems' ESP8266 Wi-Fi SoC and hardware that is based on the ESP12 module. The NodeMCU ESP8266 development board comes with the ESP12E module, which contains the ESP8266 chip with a 32-bit Tensilica Xtensa LX106 RISC microprocessor. This microprocessor supports RSRF and operates at a frequency of 80 MHz to 160 MHz. The NodeMCU has 128 KB of RAM and 4 MB of flash memory for storing data and programs. Its high processing power with built-in Wi-Fi/Bluetooth and hibernation features make it ideal for IoT projects [24]. The NodeMCU can be powered by a Micro USB connector and VIN (external power) pin. It supports UART, SPI, and I2C interfaces.

The NodeMCU expansion board can be easily programmed using the Arduino IDE as it is easy to use.

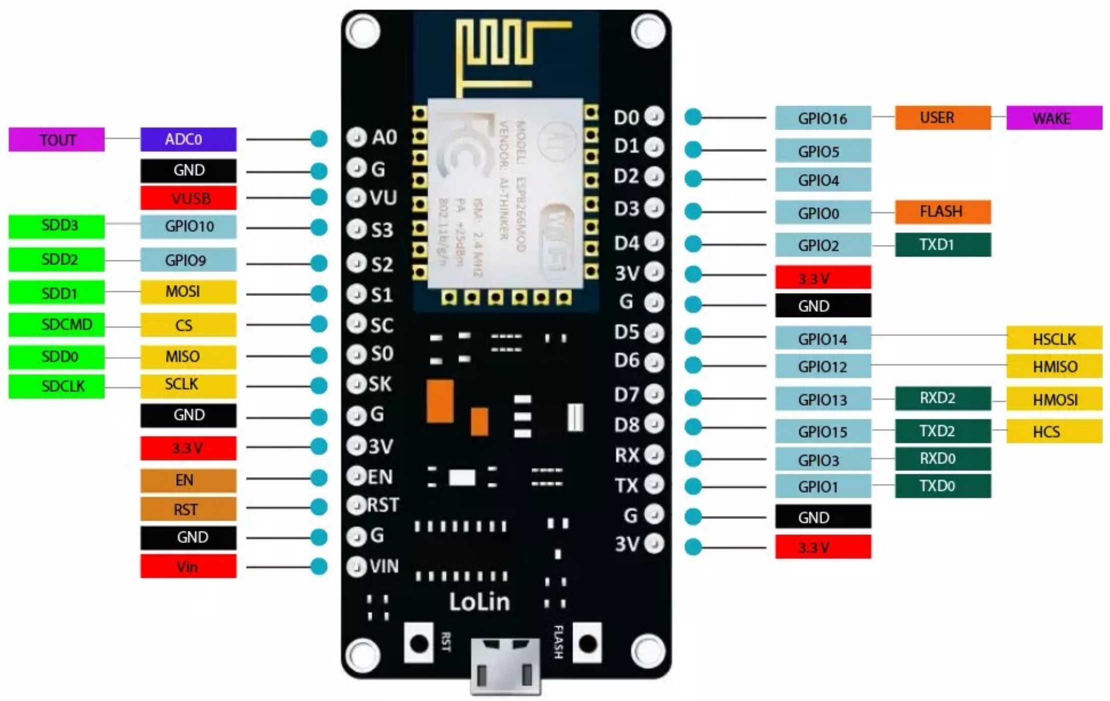


Figure 13: Appearance and pinout of ESP8266.

The advantage of using and implementing such an architecture is that it is possible to use information collection at distances greater than directly near the computer itself, while not losing data transfer speed. In addition, the data transmission channel is protected, thereby satisfying the requirements of reliability and authorized access to the microclimate control system.

3.3. Experimental tests

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 14 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.

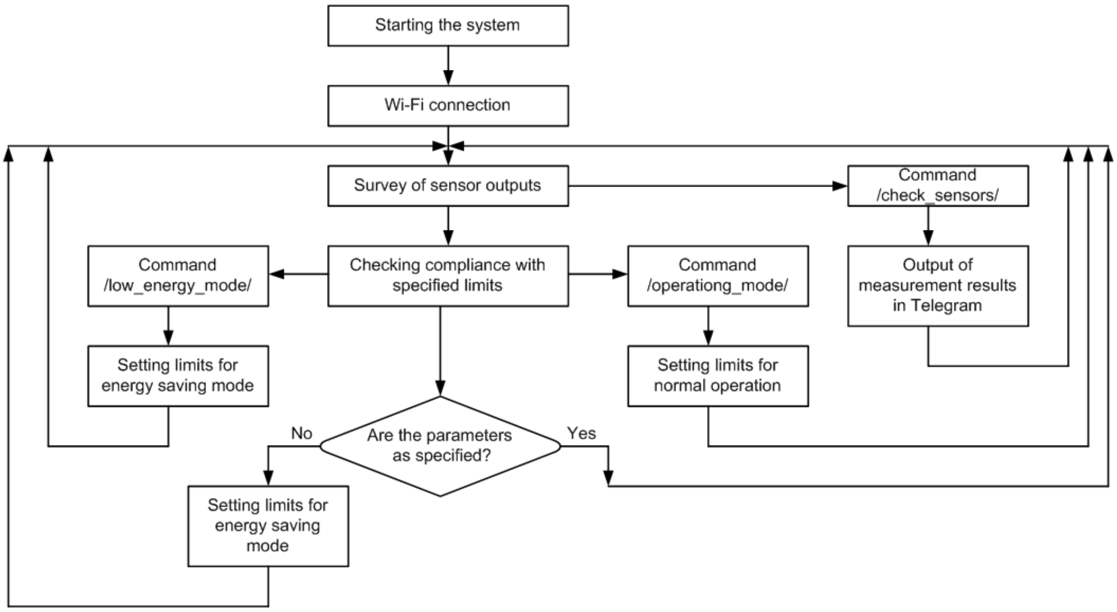
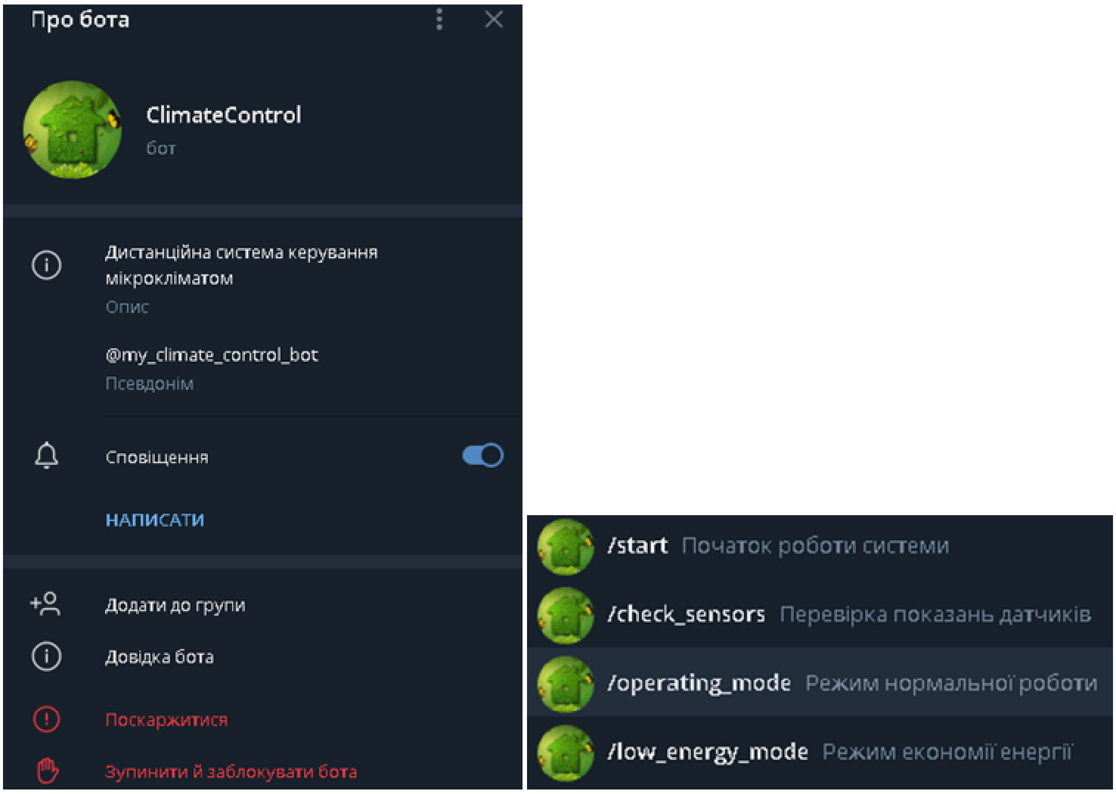


Figure 14: Algorithm of the microclimate monitoring system in educational classrooms.

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 15, and 16 show screenshots of the results of the chatbot.



Про бота

ClimateControl
бот

Дистанційна система керування мікрокліматом
Опис

@my_climate_control_bot
Псевдонім

Сповіщення

НАПИСАТИ

Додати до групи
Довідка бота
Поскаржитися
Зупинити й заблокувати бота

/start Початок роботи системи
/check_sensors Перевірка показань датчиків
/operating_mode Режим нормальної роботи
/low_energy_mode Режим економії енергії

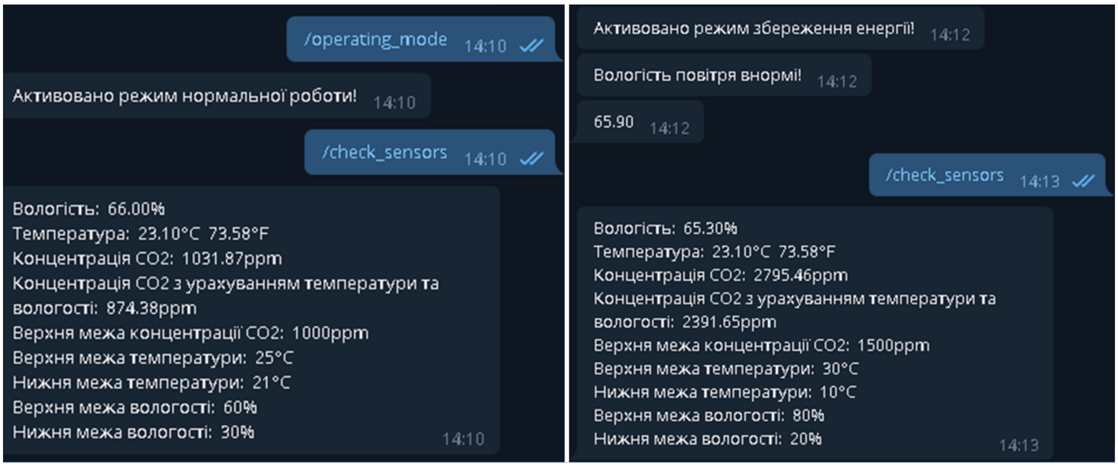
Figure 15: Chatbot “ClimateControl” and its menu.

Table 2 shows the results of the measurements illustrated in figure 16.

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.

The results of the chatbot’s response to changes in indicators above the norm are shown in figure 17 (in the system layout, the light indicator turns on).

The method of using the developed system is as follows: indicators are recorded at three points in space and the average value of each indicator is calculated. Measurements are carried out at certain time intervals: at the beginning of the lesson, in the middle and at the end of



/operating_mode

Активовано режим нормальної роботи!

/check_sensors

Вологість: 66.00%
Температура: 23.10°C 73.58°F
Концентрація CO2: 1031.87ppm
Концентрація CO2 з урахуванням температури та вологості: 874.38ppm
Верхня межа концентрації CO2: 1000ppm
Верхня межа температури: 25°C
Нижня межа температури: 21°C
Верхня межа вологості: 60%
Нижня межа вологості: 30%

Активовано режим збереження енергії!

Вологість повітря внормі!

65.90

/check_sensors

Вологість: 65.30%
Температура: 23.10°C 73.58°F
Концентрація CO2: 2795.46ppm
Концентрація CO2 з урахуванням температури та вологості: 2391.65ppm
Верхня межа концентрації CO2: 1500ppm
Верхня межа температури: 30°C
Нижня межа температури: 10°C
Верхня межа вологості: 80%
Нижня межа вологості: 20%

Figure 16: Checking the readings for the operating mode and the low energy mode.

Table 2
The results of the measurements.

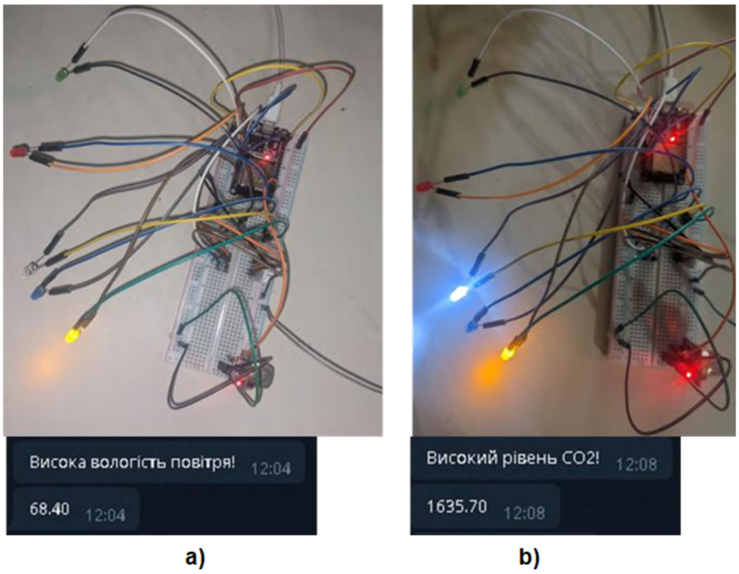
	Operating mode	Low energy mode
Humidity	66.00%	65.30%
Temperature	23.10°C (73.58°F)	23.10°C (73.58°F)
CO_2 concentration	1031.87 ppm	2795.46 ppm
CO_2 concentration taking into account temperature and humidity	874.38 ppm	2391.65 ppm
The upper limit of CO_2 concentration	1000 ppm	1500 ppm
Upper temperature limit	25°C	30°C
Lower meda temperature	21°C	10°C
Upper humidity limit	60%	80%
Lower humidity limit	30%	20%

the lesson (or readings are taken at certain time intervals during the lesson). At the same time, the relative stability of the microclimate is ensured – windows and doors are not opened, air conditioners, heaters, etc. are not turned on.

Table 3 shows an example of the results of measurements of microclimate indicators during a training session, carried out using the developed system.

Table 3
The results of measuring the parameters of the microclimate in the classrooms [11].

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/cmcm^3	436	452	420	373	415	320	250	282
CO_2 concentration, ppm	180	185	232	250	256	280	284	312


Висока вологість повітря! 12:04

68.40 12:04

Високий рівень CO2! 12:08

1635.70 12:08

a) b)

Figure 17: Light and sound alarm in the chatbot for exceeding the microclimate parameters: a) exceeding the norm of air humidity, b) exceeding the norm of CO_2 level.

At the same time, registration of the physiological indicators of the students is taking place, with the help of the second module of the developed system [24].

The next stage is the calculation of the value of the integral indicator of the microclimate and the integral indicator of the health of the collectors.

At the next stage, the relationship between the factors of the indoor microclimate and the health of the visitors is evaluated.

As a result of the collected statistics and their processing, a set of measures will be developed to ensure a healthy environment at the university.

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 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 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.

Currently, work is underway to create a web server and a database for registering measured indicators in real-time and implementing round-the-clock access to measurement results.

The developed monitoring system is part of the system for researching the influence of microclimate parameters on the physiological state of students. Another block of this system is a block for measuring human physiological parameters that respond to environmental changes and have the greatest impact on the concentration of attention, the level of information perception, and, in general, on the effectiveness of learning. The results of research carried out with the help of this system will allow to develop measures to ensure the necessary normal conditions for students' learning in closed rooms. The system is currently being tested and improved. Also, the developed system can be used to monitor the microclimate in other closed objects – offices, premises of kindergartens, schools, shelters, missiles, aircraft, tanks, etc.

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