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A.J. Alimkhanova[1], S.V. Grigorieva[1], O.Ya. Shvets[1], V.M. Sayun[2], G. Gyorok[3]
[1]D. Serikbayev East Kazakhstan Technical University, Ust-Kamenogorsk, Kazakhstan
*E-mail: aslima_alimhanova@mail.ru**
E-mail: Sgrigorieva@ektu.edu.kz
E-mail: olga.shvets75@gmail.com
[2]Tomsk State University of Control Systems and Radio electronics, Tomsk, Russia
E-mail: svm@ie.tusur.ru
[3]Obuda University, Szekesfehervar, Hungary
E-mail: gyorok.gyorgy@amk.uni-obuda.hu

DATA TRANSMISSION VIA WIRELESS OPTICAL COMMUNICATION IN INDOOR CLIMATE CONTROL SYSTEMS

БӨЛМЕДЕГІ МИКРОКЛИМАТ ПАРАМЕТРЛЕРІН БАСҚАРУ ЖҮЙЕЛЕРІНДЕ СЫМСЫЗ ОПТИКАЛЫҚ БАЙЛАНЫС АРҚЫЛЫ ДЕРЕКТЕРДІ БЕРУ

ПЕРЕДАЧА ДАННЫХ ПО БЕСПРОВОДНОЙ ОПТИЧЕСКОЙ СВЯЗИ В СИСТЕМАХ УПРАВЛЕНИЯ ПАРАМЕТРАМИ МИКРОКЛИМАТА В ПОМЕЩЕНИИ

***Abstract*.** *The article describes the concept of using LED lighting devices for data transmission in home automation systems. A scheme for organizing a system for controlling life support parameters through a light flux using Visible Light Communication technology is proposed. The capabilities of the technology allow the implementation of intelligent control systems. The paper proposes to take into account the influence of indirect indicators when adjusting parameters. Control circuits for temperature, humidity, air composition, position of windows and doors in the room have been developed. An automated control system for life support parameters is considered using the example of temperature data transmission through the LED lamps existing in the room. An experimental model has been developed. To test the proposed approach, an experimental model has been developed that implements a room temperature control system.*
***Keywords*:** *Visible Light Communication; automated control system; LED lighting; temperature mode; wireless data transmission.*

Аңдатпа. *Мақалада үйдегі автоматтандыру жүйелерінде деректерді беру үшін жарық-диодты жарықтандыру құрылғыларын пайдалану тұжырымдамасы сипатталған. Visible Light Communication технологиясының көмегімен жарық ағыны арқылы тіршілікті қамтамасыз ету параметрлерін басқарудың автоматтандырылған жүйесін ұйымдастыру схемасы ұсынылған. Технологияның мүмкіндіктері интеллектуалды басқару жүйелерін енгізуге де мүмкіндік береді. Ол үшін параметрлерді реттеу кезінде жанама көрсеткіштердің әсерін ескеру ұсынылады. Осының негізінде бөлмедегі температураны, ылғалдылықты, ауа құрамын, терезелер мен есіктердің орналасуын бақылау ілмектер әзірленді. Тіршілікті қамтамасыз ету параметрлерін басқарудың автоматтандырылған жүйесі бөлмеде бар жарықдиодты жарық көздері арқылы температура туралы деректерді беру мысалында қарастырылады. Ұсынылған тәсілді сынау үшін бөлме температурасын бақылау жүйесін жүзеге асыратын эксперименттік модель әзірленді.*
Түйін сөздер: *Visible Light Communication*; *автоматтандырылған басқару жүйесі; жарық-*

диодты жарықтандыру; температуралық режи; деректерді сымсыз жіберу.

Аннотация. *В статье описана концепция использования светодиодных осветительных приборов для передачи данных в системах домашней автоматизации. Предложена схема организации автоматизированной системы управления параметрами жизнеобеспечения через световой поток по технологии Visible Light Communication. Возможности технологии позволяют реализовывать также интеллектуальные системы управления. Для этого предлагается учитывать влияние косвенных показателей при регулировании параметров. На основе этого разработаны контуры регулирования температурой, влажностью, составом воздуха, положением окон и дверей в помещении. Автоматизированная система управления параметрами жизнеобеспечения рассматривается на примере передачи температурных данных через существующие в помещении светодиодные источники освещения. Для апробации предлагаемого подхода разработана экспериментальная модель, реализующая систему управления температурой помещения.*

Ключевые слова: *Visible Light Communication; автоматизированная система управления; светодиодное освещение; температурный режим; беспроводная передача данных.*

Introduction. The home automation system is becoming more and more popular. People want to live in intelligent “smart” living spaces, equipped with devices that interact both with a person and with each other. Such systems not only provide them with convenience, comfort, safety, but also reduce their daily expenses due to energy-saving solutions. Traditional control systems use technical solutions for wired connection of automation devices and home appliances. Implementation of such systems requires laying cables and it is most rational to do this simultaneously with the construction of a house. Currently, in home automation, wireless technologies Wi-Fi, Bluetooth, Zigbee are mainly used for receiving and transmitting data, which use the radio frequency spectrum [1-4].

For the process of data exchange and the operation of applications of “smart” systems, it is necessary to form a special environment that will provide high data transfer rates, low signal latency, and maintain a high density of subscriber devices. Wireless technologies operating in the radio frequency range are overloaded and cannot fully meet the requirements of modern life. International analytical agencies annually provide data on the number of devices connected to the network using wireless radio frequency traffic [5,6]. The forecast for the next ten years is forcing providers, manufacturers of "smart" devices and scientists to look for alternative technologies to solve impending problems.

In this paper, we propose to use the Visible Light Communication (VLC) optical wireless communication technology to control life parameters in home automation systems. VLC is a new wireless communication technology based on data transmission through LED lighting systems.

LED lamps are currently replacing universal incandescent and fluorescent lamps from our lives. The advantages of LED lighting devices are long service life, low energy consumption and high light output. The advancement of LED-based semiconductor lighting technology in lighting systems and the ability of high-power white LEDs to be quickly switched and controlled have influenced the development of optical wireless data transmission systems integrated into lighting systems. In VLC, the LED performs the functions of both communication and lighting, that is, with dual functionality.

Despite the fact that VLC technology has been developed and widely researched only for the last ten years, transmission systems with data transfer rates from 100 Mbit/s to 100 Gbit/s have been demonstrated, depending on the design of the LED, which is confirmed by research results [7-12].

In 2018, the International Telecommunication Union initiated the issue of using visible light waves for short-range communication, and the spectrum management working group presented a report on the possibility of reducing the congestion of the radio frequency spectrum. The report stated that “research on the development of new technologies in the combination of communication based on electromagnetic waves of visible light could create an interesting combination for solving problems of effective use of the radio frequency spectrum" [13].

The relevance of the topic of work is due to the need to meet the needs of a rapidly growing number of subscribers with wireless traffic with support for the quality of the required services. The research is aimed at developing applications using VLC technology for indoor communication, where it complements Wi-Fi and cellular wireless communication. The authors have previously conducted studies for possible applications [14, 15].

Materials and methods of research.

In order to properly and fully understand the use of data transmission technology with the help of powerful white LEDs for the organization of a life support parameter management system, it is necessary to form a concept. It is also worth considering the technical features of building the automation system itself using data transmission using the visible spectrum.

The system should integrate into existing control systems and complement them with its strengths, leveling the weaknesses of currently popular systems (increased radio noise, the possibility of signal interception, the final data transfer rate, etc.). An excellent analogy is the possibility of parallel use of mobile traffic via cellular networks and Wi-Fi, which in everyday life allows the user to stay "online".

VLC technology implies data transmission when lighting devices are switched on. The question arises about the energy efficiency of the system. In the residential sector of modern cities, the peak load of wireless systems falls in the evening, i.e. when the lighting system is active in the premises. The proposed approach makes it possible to reduce the noise and load of the radio frequency range at this time.

Thus, the introduction of the proposed data transmission technology does not imply complete dominance and replacement of existing technologies. It is necessary to have a clear understanding that the proposed system should work in symbiosis with existing wireless data transmission technologies.

For effective integration of the system, it is advisable to use existing lighting sources in the room. Since at the moment in the Republic of Kazakhstan it is mandatory to use LED lighting with GOST-specified parameters in a number of state institutions, such integration is quite real. Despite the fact that every citizen can use any type of permitted lighting in his personal home, there has been a steady trend in the use of LED lighting in residential buildings in the Republic over the past years. Thus, the introduction of the proposed technology is possible everywhere in Kazakhstan on the basis of ready-made infrastructure.

It is proposed to implement the construction of a life support parameter management system using data transmission technology by means of LED lighting on the principle of Master – Slave operation (master device – slave device). Since the system is limited by the possibility of sending a data transmission signal, the Master (master device) must broadcast data to all devices at once, and the Slave (slave devices) must "listen" to the master device in real time. If the Slave understands that it is being accessed, it must accept the transmitted information and execute the command without forming a response message.

The proposed control system is based on the principle of data transmission over the visible spectrum in one direction. In simple words, in a room, LED lamps on the ceiling will be part of the master device, and the slave device is not equipped with lighting elements, but only a photodetector. Therefore, the slave device will not form a response signal in the direction of the Master, but only execute its commands. This approach corresponds to the concept of building unidirectional data transmission inherent in VLC technology.

When building a stable and stable automation system for life support, it is necessary to take into account the presence of inter-circuit connections. Modern technologies allow us to take a fresh look at the principles of regulation and management and apply them to solve the problems of emerging problems.

To organize a life support management system, it is required to form control circuits for the following parameters – room temperature, air humidity, gas (air) analysis, window and door positions, light level.

The following block diagram is proposed.

The master controller is equipped with a touch panel and is located indoors. With the help of this controller, the entire control system is programmatically controlled. It is required to provide for the possibility of choosing manual control of the system and automatic operation mode.

The control unit consists of LED lighting devices and a controller. The controller is connected to the lighting devices. It is possible to carry out communication both with the help of cable products (wires) and with the help of wireless communication (Wi-Fi, Bluetooth). It is worth noting that when using wireless systems, there is both a positive side and a negative side. A positive feature is the ability to quickly integrate the system into an existing one. Additionally, such a construction will allow you to control the system remotely, but as a result, the unique increased security of the system from penetration based on data transmission technology using the visible spectrum is lost.

Interface controller. It is required to organize a data transfer interface between the receiver and the transmitter. An interface controller is used for this purpose. In an LED device, the interface controller performs a more complex function, since it is also part of the LED driver. In the receiver, the interface controller “decrypts” the analog signal received from the photodiode, brings it into the required sending format and executes the command according to the protocol.

The measuring unit includes a set of the following sensors: temperature sensor, humidity sensor, gas analysis sensor, end position sensors, light sensor. The sensors are connected to the controller and are located in accordance with existing standards and GOST standards. There are no specific requirements for installing sensors using VLC technology. The connection can also be made both wirelessly and wirelessly.

The block of the executive mechanism is considered as a set of executive mechanisms of the system. Actuators for this system: heating element, air conditioner, humidifier, forced exhaust, servos for windows and doors. The actuators are additionally equipped with photodetectors for the implementation of data transmission technology over the visible spectrum. The actuators are not interconnected, and do not have information and communication channels to communicate with each other. All intellectual work is performed by the master device, and the slave devices only obey commands.

Figure 1 shows a diagram of the described approach on the example of the organization of temperature control in the room.

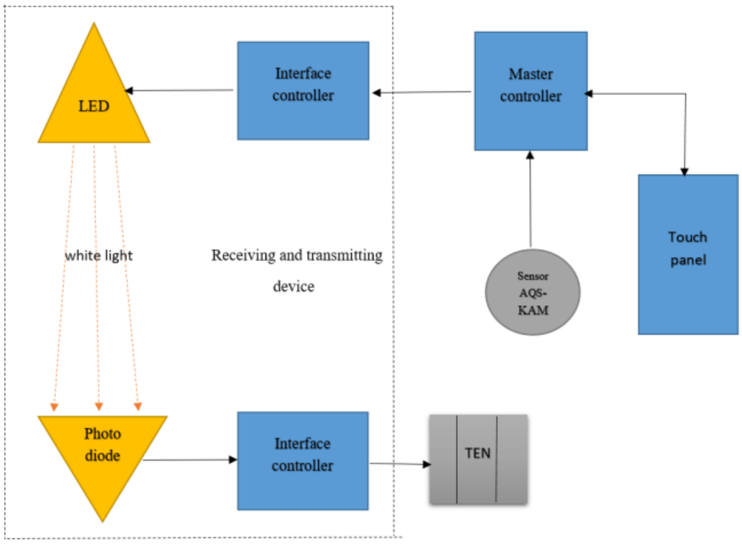

Figure 1. Scheme of automated control system temperature using VLC technology

There are several control circuits in the life support management system. All the data obtained can be divided into direct and indirect indicators for each contour. In each, highlight the possible relationship that affects the adjustable parameter. VLC technology provides for unidirectional communication in the data transmission system, so it makes sense to pay attention to indirect parameters in addition to taking into account direct control parameters during the control of each specific circuit. Despite the fact that a number of parameters do not have a clear linear relationship between each other, modern technologies allow you to process a large array of data, learn and adapt. This will eventually allow the formation of control signals by indirect actuators, ensure the stability of a particular circuit and increase the stability of the entire system.

Figure 2 shows a block diagram of the room temperature control circuit.

The following designations are introduced in the figure:

Xtemp(t), Xtemp(t) – the signal at the input and output of the temperature sensor, respectively;

Xh(t), X′h(t) is the signal at the input and output of the humidity sensor, respectively;

Xg(t), X′g(t) is the signal at the input and output of the gas sensor, respectively;

X1...position(t) ,X′1...position(t) is the signal at the input and output of the position sensors, respectively;

Ytemp(t) – control action.

The room temperature according to GOST is considered to be 18-24^{0}C, and the minimum relative humidity for human comfort and health is 30% -60%.

There is a linear relationship between air temperature and relative humidity. In winter, the outdoor air on a foggy day at 0^{0}C has a humidity of about 100%, and the heated air into the room up to 22^{0}C gives about 30% humidity.

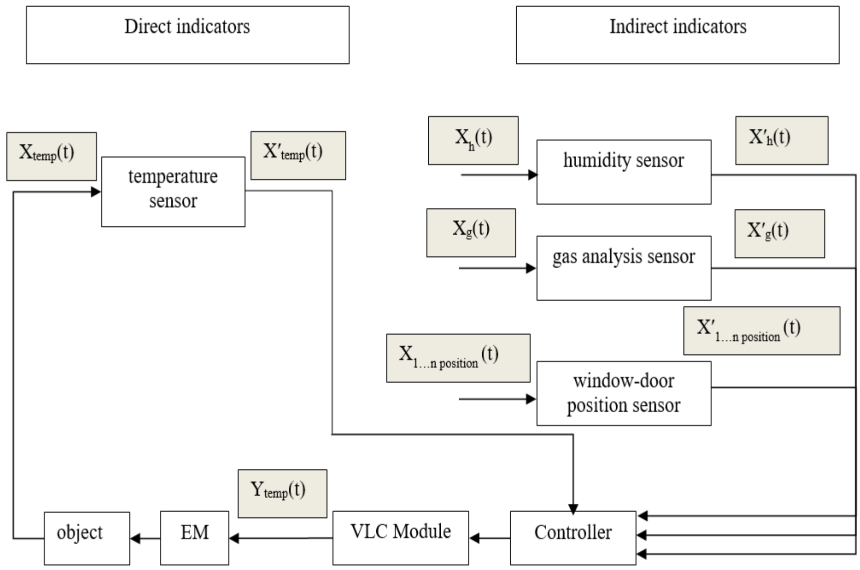

Figure 2. Block diagram of the temperature control circuit

By standards, every person who is in the room for an hour requires from 30 to 60 m^3 of clean air per hour. With the help of the sensor of the air analyzer, it is possible to obtain data on the state of the air in the room. The inflow of fresh air into the room can be provided in various ways, for example, with the help of a forced exhaust or an air conditioner. In the proposed system, ventilation is carried out by opening/closing windows. With the help of a servo, it is possible to open the window according to the specified degree of opening (percentage of opening). The end sensor is designed to check the position of the window, and as a protection against overshoot, the percentage of opening is set programmatically to the servo, and is tracked only in the zero position. It is logical that when windows and /or doors are opened for ventilation, both the temperature and humidity of the room will change.

Having made a number of assumptions, and using known linear dependencies, it is possible to calculate the behavior of the control object.

Figure 3 shows a block diagram of the humidity control circuit of the room.

According to state standards, indoor air quality is an important parameter for life support. The humidity in the room should be maintained from 30-60%.

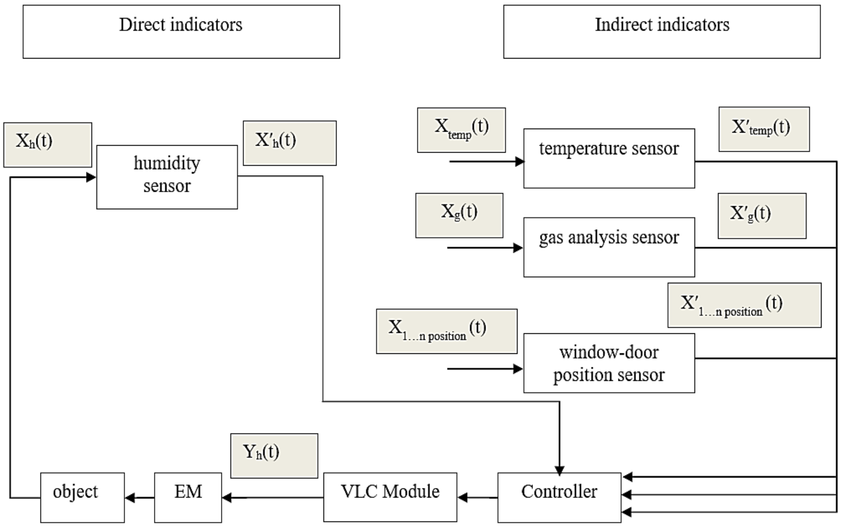

Figure 3. Block diagram of the humidity control circuit

Figure 4 shows a block diagram of the control circuit for the composition of indoor air.

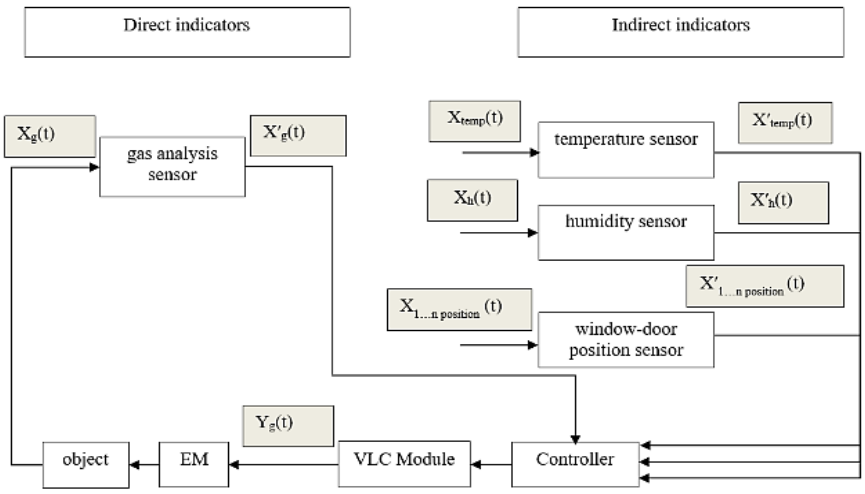

Figure 4. Block diagram of the air composition control circuit

Figure 5 shows a block diagram of the window/door position control circuit.

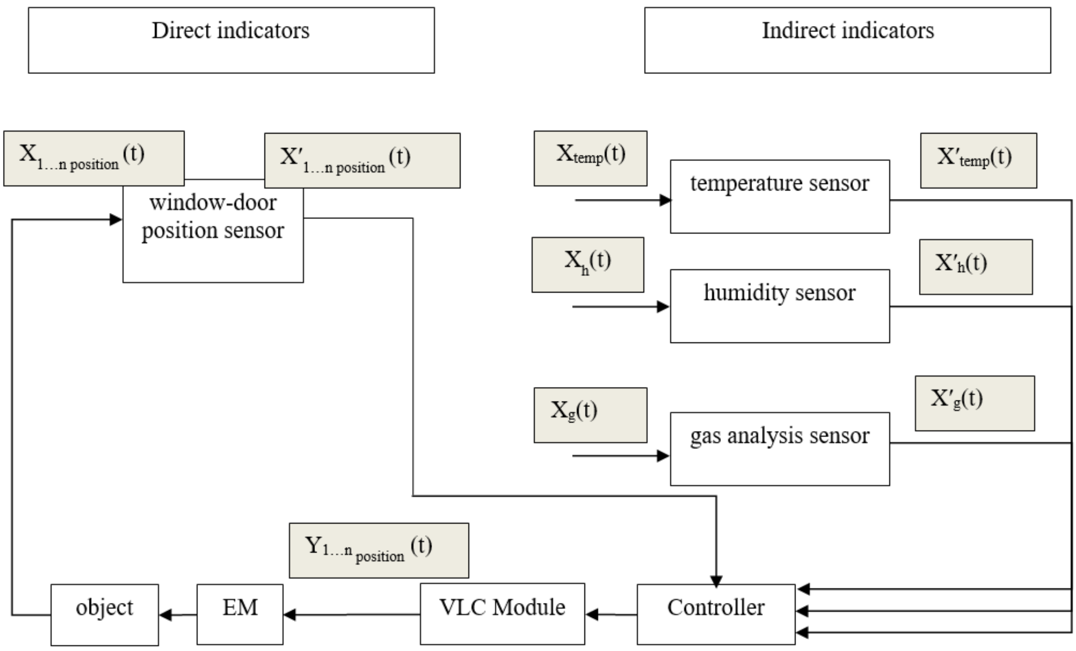

Figure 5. Block diagram of the window/door position control circuit

With this approach to building an automation system, an important step will be writing an algorithm for the operation of the system, taking into account the specific features of the control object. This task falls on the engineering staff, who will directly carry out the design, installation and commissioning works. The purpose of the work is not to provide a specific engineering solution, the scientific component, the concept and description of the process will allow the engineer to make calculations and configure the system for specific requirements. Depending on the parameters of the room and the functional purpose, both the dependencies in the formulas and the state standards for life support will differ.

Modern automated control systems can be implemented as intelligent. In our control system, taking into account in addition to direct control parameters and indirect indicators, it is possible to implement an intelligent system, since the proposed system has the following properties:

– the system has the ability to interact with the outside world using information and communication communication channels, in our case through visible light of lighting sources;

– the system is open, which allows you to replenish and acquire the necessary knowledge;

– the ability to predict the behavior of the control object (parameters) due to indirect data;

– the system has the property of compensating for inaccurate information about the state of the control object by training and implementing a new control algorithm;

– the system does not reduce the quality of functioning in case of violation of inter-circuit connections in the management process.

The advantage of intelligent automated control systems is the ability to train the system and adapt to impacts based on the analysis of the information received about the state of the control object, as well as information about the behavior of the surrounding world with which the object is in interaction. To implement such a system, it is necessary to have not only a database, but also a knowledge base, an algorithm for machine logical data entry, etc. Taking into account all the requirements for the construction of intelligent automated control systems, it becomes possible to organize the management of poorly formalized or complex technical objects by "training" the system as a whole in real time.

Results and discussion. To test the proposed approach, an experimental stand was developed that demonstrates a subsystem for maintaining a given temperature regime in a room using data transmission technology using white LEDs.

The appearance of the experimental stand is shown in Figure 6. Let us describe the connection of the elements and the algorithm for conducting the experiment.

The integrated digital temperature sensor DS18B20 is located inside the box and is connected to the transmitter module. A 3W LED matrix is used to transmit temperature data using VLC technology. A photodiode is installed in the receiving module, which receives LED pulses. The actuator is connected to the receiver and is located inside the box. Maintaining the set temperature is realized by an electric heating element with a power of 30W. Data processing and generation of control signals are carried out by Atmega 328P microcontrollers located in transceiver modules. The circuit design of the modules was developed by the authors and described in detail in [16].

The receiver and transmitter are located outside the box for the convenience of visually taking experimental temperature data. The transmitter has a display for registering the current temperature value in the box and setting the user-defined value. The receiver also has a display to record the received value from the transmitter in real time.

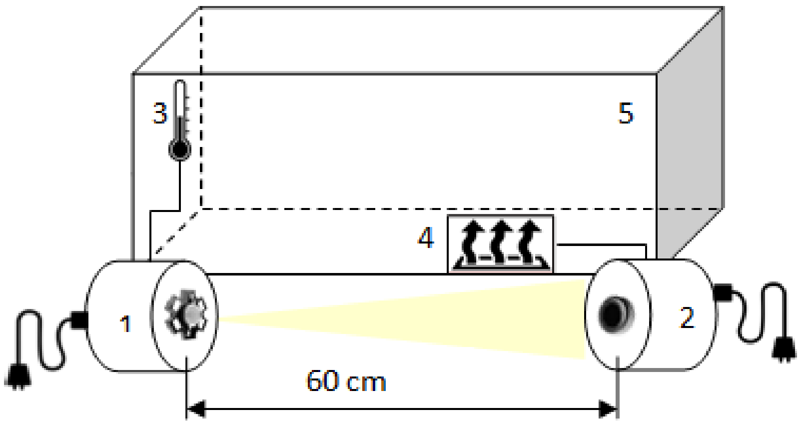

Figure 6. Experimental setup: 1 – transmitting device; 2 – receiving device; 3 – temperature sensor; 4 – heating element; 5 - room model

The following input parameters are set for the experiment.

The distance between transmitter and receiver is set to 60cm. This distance is optimal for the developed transceiver modules and has been determined experimentally.

Initial temperature inside the box t_{i0} = 26°C.

The temperature value in the duct is set to t_S = 28°C. The value was set manually on the receiver panel. Operating temperature range t_S is set to ±1°C.

The experiment was carried out indoors during the daytime with natural light.

The task was to maintain the temperature regime set by the user in an enclosed space using VLC technology to transmit controlled temperature values. The graph presents experimental data that demonstrates the process of setting the temperature setpoint (Figure 7).

The graph shows that the process goes into a steady state.

The scatter of temperature values on the graph is explained by the setting of the operating temperature range of ±1°C in the program of the receiving module, which was done for the convenience of taking readings, which were carried out visually. The use of microcontrollers in transceiver modules allows you to set values with any accuracy, depending on the technical characteristics of the actuators and the functions of the control system. Reducing the setting range is also recommended due to the possibility of efficient use of heat energy.

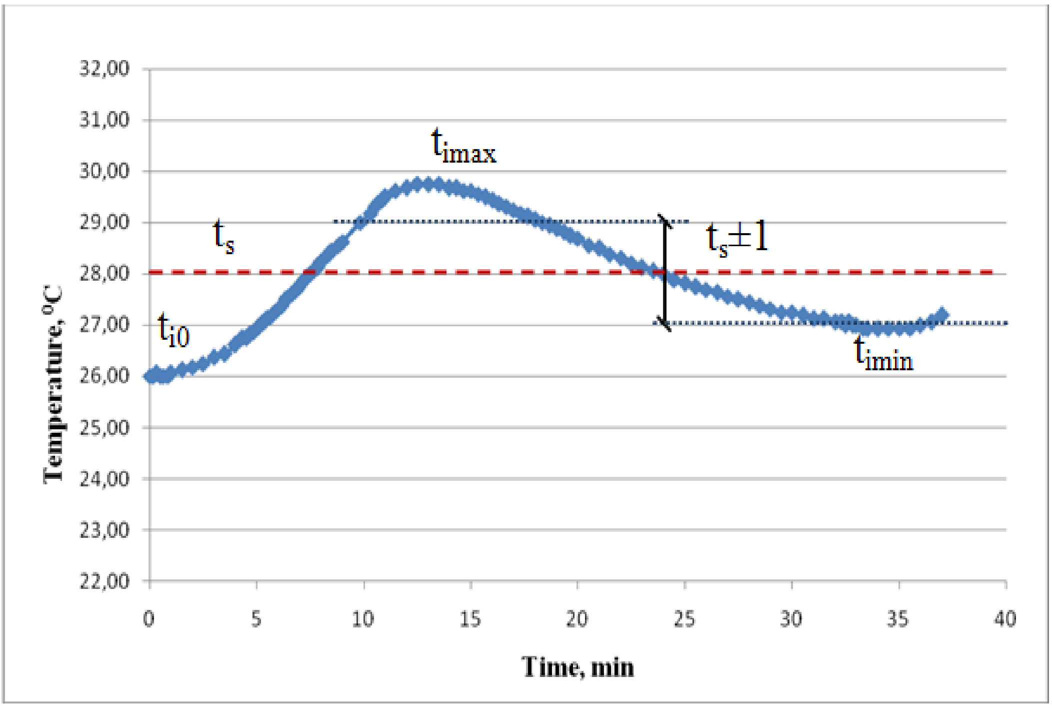

Figure 7. Temperature setting transient

The graph shows that the process goes into a steady state.

The scatter of temperature values on the graph is explained by the setting of the operating temperature range of ±1°C in the program of the receiving module, which was done for the convenience of taking readings, which were carried out visually. The use of microcontrollers in transceiver modules allows you to set values with any accuracy, depending on the technical characteristics of the actuators and the functions of the control system. Reducing the setting range is also recommended due to the possibility of efficient use of heat energy.

The duration of the process setting to a steady state during the experiment is explained, firstly, by the irreversible processes of heat and mass transfer. Secondly, we use a conventional heating element, which allows us to implement only strict control with information feedback in the system. When using an intelligent actuator, a transition to flexible control is possible, which will reduce the deviations of the controlled value.

Conclusions. The article proposes and describes a new approach to the organization of an automated control system for the parameters of life support in a room using data transmission technology by means of LED lighting. The control system is based on the principle of data transmission over the visible spectrum in one direction, which corresponds to the concept of building VLC technology. Taking into account the unidirectionality in data transmission, a block diagram has been developed. In addition to direct regulation parameters, it is proposed to take into account the influence of indirect indicators. With this in mind, the control circuits have been developed.

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