Journal of Engineering Science and Technology
Special Issue on Development of Sustainability Systems - III, 174 - 189

AUTOMATED IRRIGATION AND CLIMATE CONTROL FOR INDOOR PLANTATION IN A SMART HOUSE IN THE RUSSIAN ARCTIC

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Abstract

Due to the rapid growth of remote work and the emergence of pandemic respiratory diseases, microclimate monitoring and control of identified spaces play a very relevant role in the modernization through digitalization. The objective of this paper is to develop and assess a remote sensing and control of plants via smart approaches, like the IoT and mobiles. Methods of research included building an experimental set consisting of indoor plants. A sophisticated smart indoor irrigation system was designed and fabricated to remotely monitor and irrigate the plants via mobile control. The implemented smart system was described in detail, tested, and analysed using the collected information. The determined efficiency of the device was 65%. This study showed that the Russian market for smart devices aimed at greening and maintaining the environment is underdeveloped and requires market development and the introduction of new Russian equipment and technologies.

Keywords: Digitalization, Environmental friendliness, Health of citizens, Microclimate, Quality of life, Smart home, Smart irrigation.

1. Introduction

The Russian Federation, in the Bloomberg Innovation Index in 2020, is 26th on the list. This ranking is based on the intensity of research and development, the production of innovative services and goods, labour productivity, and patent activity [1]. Having such a high-tech power, the Russian Federation should be at least one of the top three in this rating. The Russian President Vladimir Putin ordered to work out globally competitive conditions for IT specialists. This decree is aimed at ensuring that these specialists realize their creative and entrepreneurial potential in their country [2].

The "Anywhere operations" IT model is a promising direction of industry and business. This model is aimed at more flexible user support. In this area of science, users are constantly accessing data from any device from anywhere in the world. Considering 2020, which forced employers to switch to a similar format of work, according to Gartner [3], in 3 years, about 40 percent of organizations around the world will move to the Anywhere operations model. Of course, to ensure the continuity of this model, it is necessary to provide remote connection security, the infrastructure allowing remote support and automation of individual operations. This model is primarily suitable for the industry when the employee works remotely, but not all duties can be performed online. At the time when an employee is directly at the workplace in the office, it is very important to know what is happening at their home.

The introduction of digitalization to improve the quality of life and health of citizens was carried out by many scientists. They highlighted the factors affecting the information security of smart home systems and identified modern approaches to ensuring the security of these systems [4-6]. However, the researchers [7-9] have focused on a small part of the application area, particularly on issues related to the interaction between the user and the SPA devices. Researchers [10-12] suggested that the technology would be more acceptable if it were possible to customize functionality and features. These findings have implications for the development of smart home technologies so that they are appropriate and acceptable to older people who are living independently.

Some scientists propose to monitor the deployment of large-scale sensors in a Smart City. Scientists from the city of Kurgan address the problem of cybersecurity, namely, factors affecting the security of smart home systems, and identify modern approaches to ensuring the security of these systems. Scientists from the United Kingdom developed a model that optimizes energy cost in every home, monitors energy consumption, reduces energy waste, and enables low emissions. All this shows how popular learning about Smart Home is, and the development of new devices is a pressing task.

Nowadays, "Smart Home", a trend of the IT industry, is very well developed. Figure 1 illustrates which systems are most popular in Smart Home design and application [13].

Analysis of the systems showed that 60% of residents of the Tyumen region use gadgets related to the control of lighting systems. These statistics are primarily related to the pricing of electricity in the region, as well as to the concern for the environment, by reducing electricity consumption. These systems are also the cheapest compared to the others shown in the analysis [14]. An analysis of the money that residents of the Russian Federation are ready to spend on Smart Home systems is presented in Fig. 2.

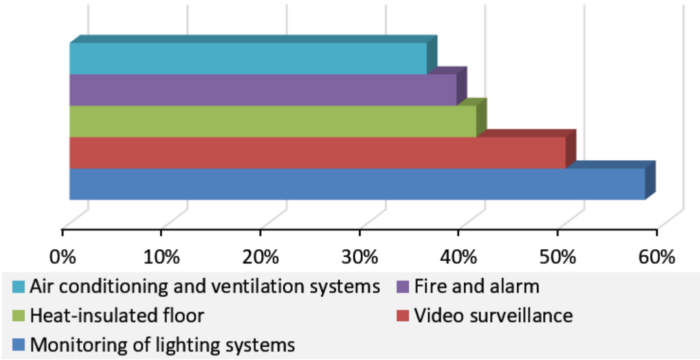

Fig. 1. Most common "Smart Home" systems using AI monitoring and control (reproduced from [13]).

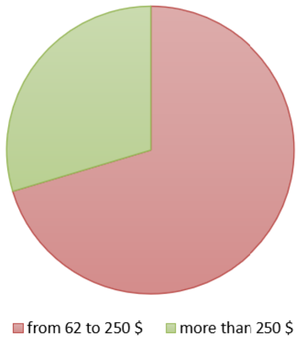

Fig. 2. Selection of the price category of smart home systems.

The diagram in Fig. 2 clearly shows that 57% of residents in the northern regions are ready to spend about 5 to 20 thousand Rubles on their comfort, while only 24% of residents are ready to spend more than 20 thousand Rubles. The market leaders of Smart Home devices were also analysed, and the data is summarized in Fig. 3 [15].

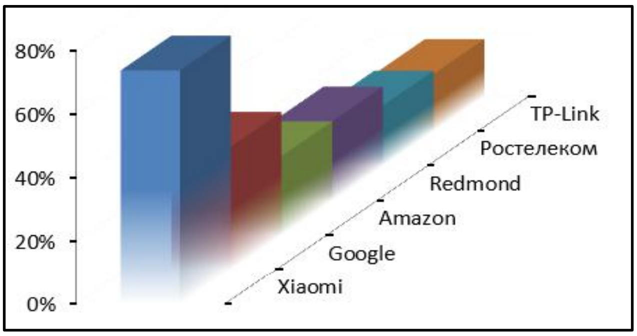

Fig. 3. Smart home market leaders (reproduced from [15]).

The Chinese company Xiaomi, with 74%, is the leader, Google is the second one, and 39%, and the rest of the representatives have a smaller market share [16]. This market analysis shows that Russian-made devices are practically not presented on the global Smart Home system devices market. Air conditioning and ventilation systems [17], as shown in Fig. 1, occupy only 34% of the market, even though these systems provide the microclimate of our apartments and the health of our citizens can depend directly on them. These systems will become more common in the decrease of respiratory disease contamination; the development of this business industry is a challenging task [18-20].

The main objective of this study is to improve the quality of life of residents of Siberia and the Far North Regions of the Russian Federation by digitalizing the life of citizens, by engineering a device that allows controlling and regulating the microclimate of residential premises for the favourable living of citizens of the Russian Federation.

To achieve the goal, the following subobjectives have been planned to be achieved:

1. To analyse the market for digitalization devices related to "Smart Home."
2. To develop a smart device for regulating the microclimate of residential premises.
3. To make a quantitative evaluation of the implementation of the device into life, using the example of residents of Siberia and the Far North.

The study introduces a new device of an automatic irrigation system using mobile control for automated irrigation and humidity control.

2. Materials and Methods

2.1. Theoretical foundation of automated irrigation

Today, a huge share of the products consumed by the population of the Earth in the modern world is provided by crop production. Crop production is one of the first and fundamental sectors of agriculture. Its role in the development of the economy and even the entire humanity cannot be overestimated since it is the food security of any country. The population's food security depends on its development.

With the growth of the population, it is necessary to increase the turnover of products in the crop industry and to improve the conditions for growing fruits to get the maximum return. One of the most important conditions is water. It must be constantly maintained at the same level so that the plant can feed. Currently, automatic watering systems are used to automate this process, which, due to the control program and the actuator part (valves), automatically maintains humidity at the required level. A good set of automatic irrigation systems allows you to eliminate the labour costs in the process of watering plants, which greatly simplifies care and even increases yields.

So, it can be concluded that this kind of digitalization positively affects a person's quality of life. This technology has become successful and is already integral in applications, both in large town areas and in small ones. However, good installation of an automatic irrigation system is still considered to be expensive, and in this regard, small companies and even private gardeners may abandon this technology. To solve this problem, the task was set to develop a new, unparalleled automatic irrigation system device in the market of the Russian Federation. This device must meet all environmental standards, must be cheaper than its foreign counterparts, and must have expanded functionality and reliability.

The new device is a universal automatic irrigation system that meets the following technical and technological parameters: autonomy; remote use via telephone; precise control of plant conditions (temperature, soil, and air humidity); versatility; relatively low cost; potential for further improvement; and environmental friendliness. To determine the technical characteristics of the new device, it is necessary to analyse the existing irrigation methods and systems. This analysis will determine the final functionality, components, and scope of application of the developed device.

Literature analysis has shown that there are three varieties of systems for delivering nutrient moisture to plant nutrition systems. For clarity, the diagram shown in Fig. 4 was designed.

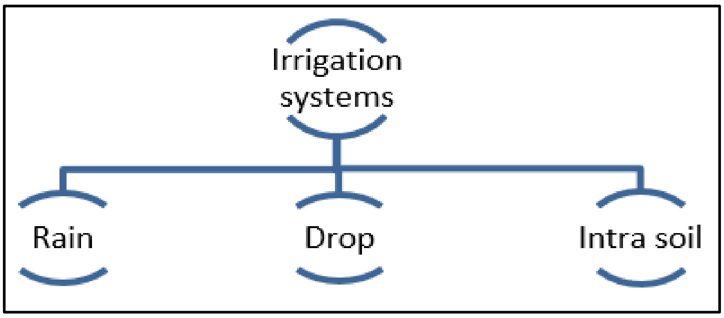

Fig. 4. Diagram of irrigation systems.

Another name for this system is pointing watering. The main advantage of this type of system is low cost. Water with a small head is supplied through hoses from an autonomous structure (a tank filled, for example, from a well) and through droplets directly to the roots of plants [21]. The supply of liquid from the water tank to the plants is carried out on special ribbons laid on the surface of the soil. Next to each plant, there is its own hole for the removal of moisture.

There are two options for providing a drip system: either you independently make holes and fit drips, or it is easier to purchase a special hose, inside which is a special capillary labyrinth that provides a slowdown in the flow of water and its exit through droplets. This device is called drip tape [22, 23].

One type of drip watering is micro watering. It is distinguished by its low water consumption (achieved due to microscopic drops) and is most often used in mini greenhouses on urban balconies, for flowers in pots, or in winter gardens.

The rainwater method simulates the natural conditions of the environment when plants are watered with raindrops [24, 25]. In this case, absorption occurs not only by the roots of planted crops, but also by the surface of the leaves. The liquid is transferred from the water tank through separate hoses, after which it falls into sprinklers, which can be located under the roof of the structure or at the ground level. Small drops of water enter the ground and irrigate the soil well on the beds.

Internal soil sprinkling is similar in structure to drip sprinkling, with only one difference-feeding hoses are located under the soil layer. This option of soil moistening is great for those cases when the crops grown do not tolerate a wet environment. The system provides underground hose wiring with thick walls. Water is supplied from each hose directly to the roots of crops. The advantages and disadvantages of each possible option are presented in Table 1.

Table 1. Advantages and disadvantages of each system.

Type of irrigation system	Advantages	Disadvantages
Drop	The belief of over-wetting the soil is significantly reduced, and water is saved (up to about 30% compared to standard watering). All water goes to the plant.	They need to use only clean water, since the slightest impurities can clog the drip tapes.
Rain automatic watering	The possibility of using only one sprayer to irrigate a large section of the bed. Dose-bath liquid supply. An additional advantage of this system is the increased humidity in the greenhouse, which is especially important for a number of crops.	The possibility of an excessive increase in humidity in the greenhouse and the appearance of sunburn on the leaf plates of plants (appears because of drops on their top). Such a microclimate is an appropriate one for weeds.
Internal watering	The most effective irrigation system, which, in addition to moistening the soil, also improves its aeration. An important advantage is that the ground on the surface does not wash, and therefore does not form a hard crust, which must be regularly loosened.	The difficulty of arranging the irrigation system is largely due to the need for soil excavation in the greenhouse. Water entry ports are often sucked in.

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2.2. Explanatory hypothesis

The automatic irrigation system is a specialized technical complex capable of independently providing uniform, regular watering of a specific area. The system consists of special sprinklers, various valves, cranes, hoses, a pump, sensors, and a small controller that determines the need for irrigation and acts according to the program laid down in it. The automatic irrigation system operates under certain conditions, which are introduced into the control program.

The device being engineered should be universal. The device shall be suitable for any embodiment of the device. Field tests of the developed device were carried out using a drip irrigation system. Irrigation activation methods could be one of the presented methods in Fig. 5.

During the study, a scientific assumption was made about the possibility of creating a device supporting the microclimate of indoor plants with the ability to be controlled by a smartphone. For further work, it is necessary to determine the logic of the new device and controller.

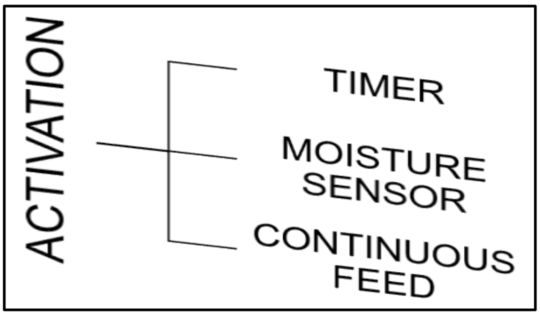


Fig. 5. Irrigation activation methods.

2.3. System components

The selected elements must comply with the specifications chosen by the authors. The controller acts as an automatic fuel control system. Initially, we considered creating a controller based on Arduino nano, but in the end, it was decided to use ESP8266 since it allows you to manage the device remotely using a WI-FI network. For clarity, a list of components was compiled, from which a new device was designed and assembled. The components were grouped and listed in Table 2.

Table 2. Components of the developed automated irrigation management device.

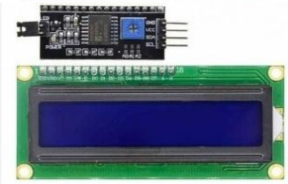
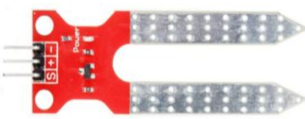
No.	Description	Photo
1	ESP8266 on the node MCU board. Acts as controller	
2	LCD 16 × 2 display with I2C module.	
3	Soil moisture sensor type: capacitive Supply voltage: 3.3 - 5 V Current consumption: up to 6 mA Interface: analogy signal Output signal range: 0.5 - 3.3 V Depth of immersion in soil: up to 80 mm Dimensions: 118 × 20 × 7.6 mm	
4	Atmospheric humidity and temperature sensor Operating voltage: 3.3 V Pressure range: 300-1100 hPa Temperature range: -40 to + 85 °C Humidity range: 0 - 100% Average power consumption: 2.74 mA, in sleep mode: 0.1 mA Mean measurement time: 5.5 ms Pressure measurement accuracy: 0.01 hPa Temperature measurement accuracy: 0.01 °C Connection interface: SPI buses Size: 152 × 120 mm	
5	Real-time clock, for autonomous timer control Supply voltage, 12 V Minimum billing time/delay, sec 1 Maximum billing time/delay, h 24 Consumption current in mode, mA 50 ADC input voltage, V 0-5 Relay power on, 40 W Maximum number in 9999 counter mode Operating temperature, -30 to +50 °C Module dimensions, mm 76 × 47 × 15	
6	Relay Supply voltage: 5 V Input current: more than 100 mA Load: 10 A	

Figure 6 shows the graphical diagram of the components' connection, that is, the logic of the operation. The device, shown in Fig. 7, was engineered according to all the rules for compiling electronic systems. The circuit consists of several blocks. Each unit is responsible for its own functionality.

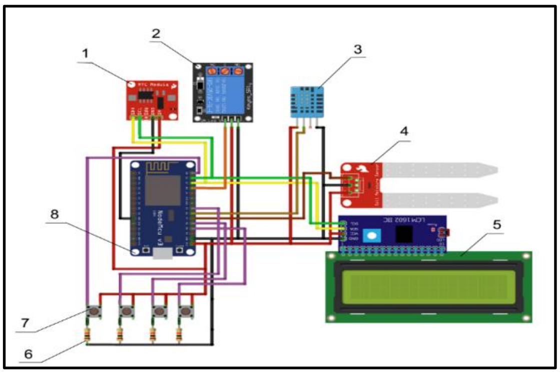


Fig. 6. Graphical diagram of device connection. (1) RTC module, (2) Relay, (3) Atmospheric humidity and temperature sensor, (4) Soil humidity sensor, (5) LCD, (6) the resistor, (7) button, (8) ESP8266 on the node MCU board.

2.4. Measuring instruments

To enter the market, the device must comply with all ethical and aesthetic standards. That is why it was decided to develop the body of the device. The model was built in Autodesk Fusion 360. The model made it possible to write software code for creating a case using additive technologies.

The case was made of white ABS plastic using 3D printing. The layout of the finished product is shown in Fig. 7. This type of case production is sufficient for our tasks. The case meets all requirements, including strength, resistance to external influences, and environmental friendliness.

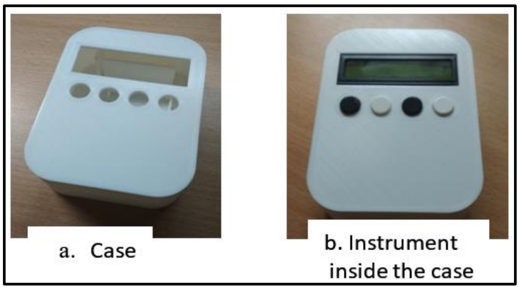


Fig. 7. The case is made using additive technologies. (a) - Case after printing, (b) - Case with an engineered device installed inside.

2.5. Software method

The main feature of the controller is the ability to control using a smartphone connected to a WI-FI network, as well as obtaining accurate soil moisture readings. A remote control allows us to control the state of crops, for example, while on vacation, abroad, or rather, wherever there is an Internet connection. This feature allows you to include the device in the list of smart devices in the smart home.

The great advantage of these modules is the ability to remotely control the microcontroller from the phone in many ways: via Bluetooth, Wi-Fi, SMS, etc. Android program dialog box as shown in Fig. 8.

Fig. 8. Android program dialog box.

The project requires control from anywhere in the world, so Bluetooth connection is not suitable. It is also desirable to minimize maintenance costs; therefore, installing a SIM card with Internet access in this case is also not suitable. Wi-Fi connection suits best, since Wi-Fi networks are everywhere and connecting the device does not require any additional costs.

Wi-Fi management provides services such as MQTT, Blynk, Virtuino, and others. They offer a cloud server and data transfer between the microcontroller and the phone. Blynk was used in this project due to its beautiful design, convenient management, and flexible interface configuration, as small projects like this are free, which plays an important role.

The second large unit of the device is the power supply. The maximum need for water was predicted to check the capabilities of the water source, the selection of the filter station, and the rest of the fittings. We will use known formulas.

$$Q = \frac{60m^3/ra*S}{\mathrm{T}*10{,}000} \tag{1}$$

where Q is the filter station, m^3/h; S is the planned irrigation area, m^2; T is the planned operating time of the system per day, 16-20 h.

The required irrigation pipe for each crop, considering the cultivated area and planting scheme, is calculated using Eq. (2).

$$Lt = \frac{Sk*10{,}000}{s} \tag{2}$$

where Lt is the length needed for an irrigation tube, m; Sk is the area of the cultivated crop; and s is the distance between the irrigation tubes (m).

To determine the water flow rate per hectare, the following dependence, m^3/h, is used:

$$W = \frac{10*q}{s*x} \tag{3}$$

where s is the distance between irrigation tubes (fit diagram) (m), x is the distance between emitters of irrigation tube (m), and q is the pouring rate of one emitter (l/h).

2.6. Testing procedure and data collection

It was decided to conduct field tests on indoor plants. These studies are aimed at testing the industrial patency of the device, determining the efficiency and reliability of the engineered device. The study involved three types of flowering plants. Drip tubes were applied to all three plants, as shown in Fig. 9.

Fig. 9. Field tests of the engineered device.

The developed device was in proximity to the plant, as shown in Fig. 10. The device was controlled using a mobile communication protocol over the internet, with pre-installed software complex and connected via a wireless communication channel with the device. Commands were sent directly from the App on the mobile phone.

Fig. 10. Device control via mobile App.

3. Results and Discussion

Existing methods of irrigation of flowering plants in the market have been analysed. The most effective one was chosen. It is proposed that the developed device has no analogues in the Russian market of smart devices.

3.1. Field tests

A field test of the developed device was carried out. As a result of field tests, an analysis was carried out of various types of maintaining plant humidity. The measured relative humidity by manual watering and by the system is shown in Fig. 11. The Blue line shows the humidity maintained using an automatic irrigation device. Red stands for maintaining humidity manually. According to the schedule, we see that during the day, the percentage of moisture in the air gradually drops. When using the engineered automatic irrigation device, the percentage of humidity in the air drops within a certain interval specified by the operator according to the program. Further, irrigation is carried out, and humidity grows to the desired value; thus, the cycle is repeated.

During the study, two methods of maintaining humidity were compared: manual watering and an automatic watering system (AWS). In both cases, watering was performed 120 minutes after the start of the experiment. In the case of manual watering, there was a significant decrease in the humidity level to its initial value within approximately 24 hours. This indicates that the optimal humidity level for plants was not consistently maintained. At the same time, the automatic irrigation system demonstrates higher efficiency in maintaining the required humidity level.

As shown in Fig. 11, the watering itself in both versions was carried out 120 minutes after the start of the study. Analysing the manual watering schedule, humidity drops to an initial level in about a day, while the auto-watering system does not allow humidity to drop below 40%, maintaining it in the range of up to 65%.

Analysis of the graphs indicates that the SAP operates cyclically. The percentage of moisture in the air decreases within the range specified by the operator in the program. When the humidity level reaches a certain threshold, the system activates the irrigation system. A statistical analysis of field tests was conducted using descriptive statistics, which determined the effectiveness of the developed device to be 65%.

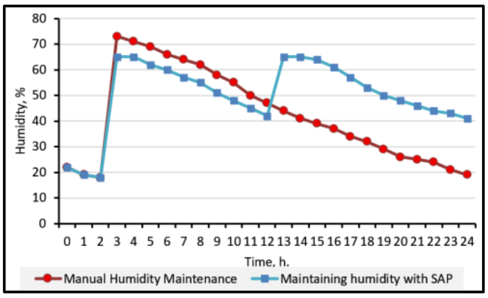


Fig. 11. Moisture measurement results with and without automated irrigation.

3.2. Key features of the developed system

After analysing known types of soil irrigation systems, drip irrigation was chosen as the most suitable for our study. This type of irrigation is the most unexplored from a technological point of view, which makes it necessary to study this type of irrigation in detail and offer a solution to the problem. Drip watering, like other types of watering, has both several disadvantages and several advantages over other irrigation systems currently known in the world. The most common advantages of this system are the following:

- Does not injure the system of seed reproduction. When watering by sprinkling, the jet of nutrient liquid is ejected at a high speed for a long distance.
- Does not cause burns on the external organs of plants. Water sprayed in different directions enters the organs of plants. Ultraviolet radiation from the sun can cause irreparable damage to the external organs of plants if there is liquid on the external surface at that moment, which acts as a magnifying glass, thereby leaving burns to the organs of plants. Drip tubes are the safest method of irrigation in this case, as they deliver liquid directly to the plant's roots. Plant burns in this case are not possible, which is a huge advantage over other systems, especially when it comes to very rare and ridiculous plants.

- Uniformity of power supply. In this way of plant nutrition, moisture is supplied through drip lines, thereby saturating the soil. With this type of nutrition, moisture differences, root pouring, etc., are excluded. Nutritional stability is the key to a healthy, strong plant.
- Effectiveness of soil moisture feeding method. With an artificial food system, all moisture directed to feed the plant is absorbed by it. With natural nutrition, for example, when it rains, up to 50% of moisture evaporates in the atmosphere, as well as from the external organs of plants, by natural weathering, moisture is blown away, and the plant does not receive the moisture necessary for life.
- The drip system is cheaper than installing sprinklers, and the reduced water consumption allows you to further reduce costs and increase the efficiency of drip watering.
- Relative simplicity of design. No additional compressors are required to implement this system. It is necessary to have about 0.2 - 0.3 MPa for a continuous power supply. At the same time, the operation of sprinklers requires 1.5 - 2 times more pressure, about 0.4 - 0.6 MPa.
- Possibility of use in complex geological conditions. The design of the drip method includes drip belts, which, due to their flexibility, allow installation in such complex areas as hills, depressions, and level differences.
- Installation mobility. In the event of a change in the layout of the lawn from last season, the mobility of the plant will allow you to easily set it in a new place.

Nowadays, there are smart devices with separate types of watering activation on the market. We faced the task of engineering a new device with no analogues on the market, ensuring it would be universal. The device's versatility includes support for all types of activation. The device provides for the selection of the operation mode in the category selection menu.

As a result of the study, a literary analysis of the market for digitalization devices of Smart Home was carried out, which showed the need to increase the range of smart devices manufactured in industrial areas of the Russian Federation. The market analysis is shown in Fig. 12.

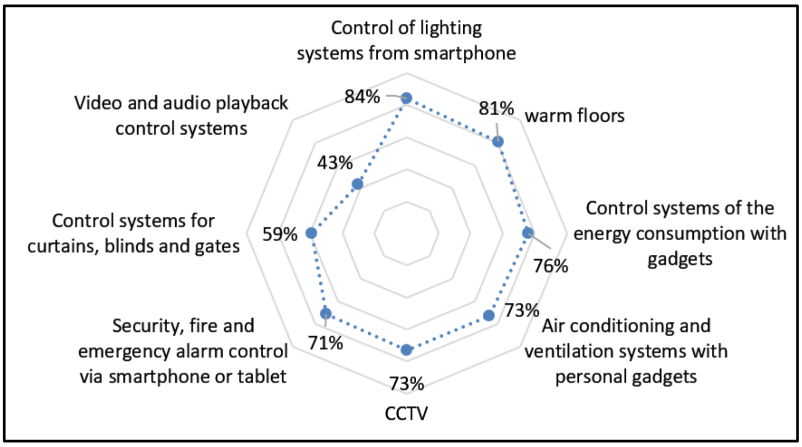


Fig. 12. Requirements of smart home in the Russian federation.

4. Conclusions

This study showed that the Russian market is lacking in smart devices aimed at microclimate control. In turn, these devices must meet all environmental standards created in industrial areas of the Russian Federation, with the possibility of entering the markets of other countries. The study confirms the effectiveness of the engineered device of automatic irrigation.

- As a result of the study, a literary analysis of the market for digitalization devices of Smart Home was carried out, which showed the need to increase the range of smart devices manufactured in industrial areas of the Russian Federation.
- Existing methods of irrigation of flowering plants have been analysed. The most effective one was chosen.
- A new device for automated irrigation has been developed. Tests of the engineered device were carried out. A statistical analysis of field trials was carried out, which showed the efficiency of the developed device of 65%.

An analysis of the market situation indicates that a segment of intelligent devices focused on environmental improvement and the maintenance of a sustainable environment in the Russian Federation is in its infancy. The identified vacuum demonstrates the urgent need for targeted development of this industry and its saturation with competitive products of domestic development, which is not only an economic need but also an important step towards technological sovereignty in the field of green technologies.

5. Research Limitations and Direction of Further Research

This study has completed the initial phase of developing and testing a technology to improve control efficiency and maintain an optimal microclimate for indoor plants. Within this phase, a functional prototype of the device was developed, and laboratory and field tests were carried out, confirming its operability and operational efficiency.

The results provide a solid scientific and technical foundation for the transition to the next phase of work, which will be focused on scaling the solution. The strategic objective is to adapt the technology for use on an industrial scale, particularly in large-scale greenhouses.

The development and implementation of a network architecture have been identified as an immediate tactical task towards this goal. The next key step will be the integration of several devices into a single management network, which will allow us to explore issues of synchronization of their work, centralized control, allocation of resources, and improvement of fault resistance of the system. The implementation of this task will open opportunities for creating integrated climate-control systems, which is a logical development of this study and corresponds to the global trend of the Internet of Things (IoT) in agricultural technologies.

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