Efficiency of Smart Heating Module for Domestic Greenhouse

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***Abstract*— The article is devoted to the development of an autonomous energy-efficient greenhouse microclimate control system based on the Node-RED platform using solar energy. The proposed solution provides automatic control of ventilation and heating based on the analysis of temperature, illumination and power supply status, which allows maintaining optimal growing conditions with minimal energy consumption. The advantages of the system are autonomy, adaptability to changes in external conditions, modular architecture and accessibility of implementation, which makes it promising for use in small and medium-sized greenhouse farms in rural regions.**

Keywords*— *control system, solar energy, power source

I. Introduction

Modern greenhouse farming is characterized by increasing demands for resource efficiency and quality of microclimate management. Traditional approaches to temperature, humidity, and light control often do not provide the necessary accuracy and adaptability in conditions of changing external influences, which leads to irrational use of energy and water resources and a decrease in the efficiency of agricultural production. In this regard, the implementation of intelligent control systems that can monitor and optimize microclimate parameters in real time based on modern algorithmic methods is of particular relevance. An additional challenge for greenhouse production is climate change, which negatively affects the yield and quality of vegetable crops due to increased heat stress, changes in precipitation patterns, and increased pest infestation. The works [1–4] substantiate the need for the agricultural sector to adapt to these challenges by improving breeding approaches, increasing the efficiency of resource use, and implementing modern technologies [6, 8, 9]. Research [5] is devoted to the issues of long-term planning in vegetable growing. In [7] it is shown that sensor systems provide effective monitoring of the state of the soil, plants and the environment, and modern communication protocols support reliable data transmission. The results of research [10] show that the integration of sensors, wireless networks and data analytics is a key prerequisite for accurate microclimate control and rational use of resources. In addition, in [12] the application of sensor technologies as a tool for increasing food security is considered. The practical effectiveness of IoT approaches for agriculture has been confirmed in [13–15]. Field research results [16, 17] demonstrate an increase in yield and resource efficiency through the use of intelligent control systems. At the same time, the increase in the cost of energy carriers, climate change, and the need for sustainable development of agricultural production necessitate the implementation of autonomous energy-efficient solutions. This is especially relevant for greenhouse farms that require continuous microclimate control in conditions of unstable power supply [18]. In [19], it is emphasized that increasing the energy efficiency of greenhouses is achieved through a combination of thermal insulation solutions and intelligent control systems.

This work proposes an autonomous system for energy-saving control of greenhouse ventilation and heating based on the Node-RED platform using solar energy as the main power source. The system provides automatic adaptation of operating modes to temperature, illumination, and power supply conditions, maintaining the necessary microclimate parameters with minimal energy consumption. The solution architecture includes a solar panel, a battery, a charge controller, temperature and light sensors, ventilation and heating actuators, and a controller based on Raspberry Pi. Based on the results of previous studies [21–23], the work implemented autonomous power supply of the system taking into account the battery charge level and lighting conditions, and also developed a graphical monitoring interface in the Node-RED environment for monitoring temperature, ventilation status and

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This demonstrates that even a relatively small increase in the average daily temperature has a significant effect on the growth rate of young greenery, since the culture reacts sensitively to exceeding the base temperature level (approximately 5 °C).

The results obtained indicate that the smart ventilation installation performs not only the function of cooling in the warm period, but can also be used as a means of optimizing the temperature field in the cold season. The mechanism for increasing efficiency is based on improving air mixing and reducing heat loss, which is especially important in small greenhouses with local temperature differences. An increase in the average daily temperature by even 1–2°C in early spring can shift the date of the first harvest 7–10 days earlier, which increases the profitability of the greenhouse economy and ensures a more stable supply of products.

CONCLUSIONS

The conducted model experimental studies confirmed the effectiveness of the intelligent ventilation system, which provides an increase in the average daily temperature in the greenhouse by 1.3–1.4 °C in the early spring period and contributes to an increase in the conditional yield of early greens by approximately 48%. It was established that controlled ventilation evens out the temperature profile in the greenhouse, and even minor changes in the microclimate have a significant agronomic effect. The developed system is implemented on the Node-RED platform, is characterized by scalability, modularity and the ability to integrate with various types of sensors and actuators, which ensures its versatility and suitability for expanding the functionality. Further research should be directed towards conducting long-term field experiments with extended monitoring of environmental parameters.

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