Science, Engineering & Education, 10, (1), 2025, 51-60

Automated Climate and Irrigation Control System in Greenhouses via IoT

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Received 05 May 2025, Accepted 17 October 2025
DOI: 10.59957/see.v10.i1.2025.7

ABSTRACT

This study presents an IoT-based automated system for managing key parameters in a greenhouse for crop cultivation. The system aims to enhance operational efficiency, increase yields, and reduce labour and operational costs through process automation, resource optimization, and improved product quality. Implementing IoT technologies in a small, automated greenhouse can transform it from a conventional agricultural setup into a high-tech production facility that is more sustainable, efficient, and profitable. This article discusses the fundamental principles, methodologies, and technical components employed in the development of the system.
Keywords: IoT technologies, Esp32, Programmable logic controller, Flprog, Remotexy.

INTRODUCTION

Climate change and the growing global population pose significant challenges to the agricultural sector, increasing the demand for more efficient cultivation methods to enhance crop yields. One of the primary approaches to achieve these objectives is the controlled cultivation of crops in various types of greenhouses, which allows for the maintenance of optimal growth conditions [1]. Often, due to the nature of the components used and the system architecture, such automation solutions remain inaccessible to producers because of their high cost. The complexity and the need for specialized maintenance justify the development of accessible, easily deployable, and adaptive solutions. IoT systems, implemented using technical devices and open-source software components, represent an alternative to expensive industrial solutions. These systems provide opportunities for process automation in crop cultivation (irrigation, ventilation, lighting), data analysis, and prediction through communication and direct access to data from multiple sensors and modules, as well as capabilities for real-time monitoring and control [2]. A mobile application has been developed using the RemoteXY cloud platform.

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EXPERIMENTAL

Temperature and humidity control system

The management of the ventilation system is one of the key factors for controlling the greenhouse climate [3, 4]. It is implemented based on a two-position logic (ON/OFF) within the FLProg environment, utilizing temperature and humidity data provided by the SHT20 sensor (Fig. 1). Threshold values for air temperature and humidity are defined and compared with the measurements received from the sensor. Hysteresis modules (HYST2 and HYST4) prevent frequent switching around the threshold values. An OR logic block combines the two conditions (temperature or humidity exceeding the limits), enabling fan activation when any of the parameters deviates from the set values. An AND module integrates this signal with a manual override (switch exhaust fan), allowing operator intervention. The output signal controls the Exhaust ON/OFF block, which triggers the relay channel (pinout D33), activating the fan and an LED indicator reflecting the status. The control of the intake ventilation system, as well as the heating management, is realized using an identical logical architecture to that of the exhaust fan.

Irrigation control system

For the automation of the irrigation process, a capacitive soil moisture sensor was employed [5]. The sensor readings were converted into percentage values using a nonlinear scaling function, which compensates for the reduced sensitivity at the extreme measurement ranges, ensuring accurate moisture assessment (Fig. 2).

The control system comprises discrete functional blocks that perform the core operations of measurement, data processing, and the application of pre-defined algorithms for managing the actuators (Fig. 3).

The irrigation control algorithm begins with the generation of an analog signal from the capacitive soil moisture sensor (soil moisture sensor 2(VP)), which is converted into digital values in the range 0 - 4095 via the embedded 12-bit ADC of the controller. The acquired data are processed through a moving average filter (SredQuard / effective signal value estimation) to mitigate the effects of transient disturbances. Subsequently, a nonlinear scaling block (Polygon) maps the ADC values to pre-defined inflection points, providing a percentage-based estimation of soil moisture. The system operates in two control modes: automatic and weekly-timer

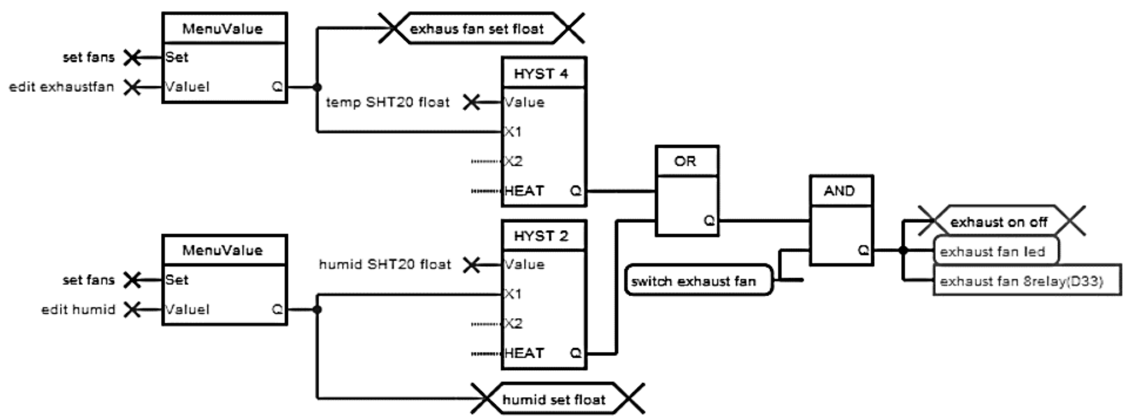

Fig. 1. Logic diagram for the control of the intake ventilation system.

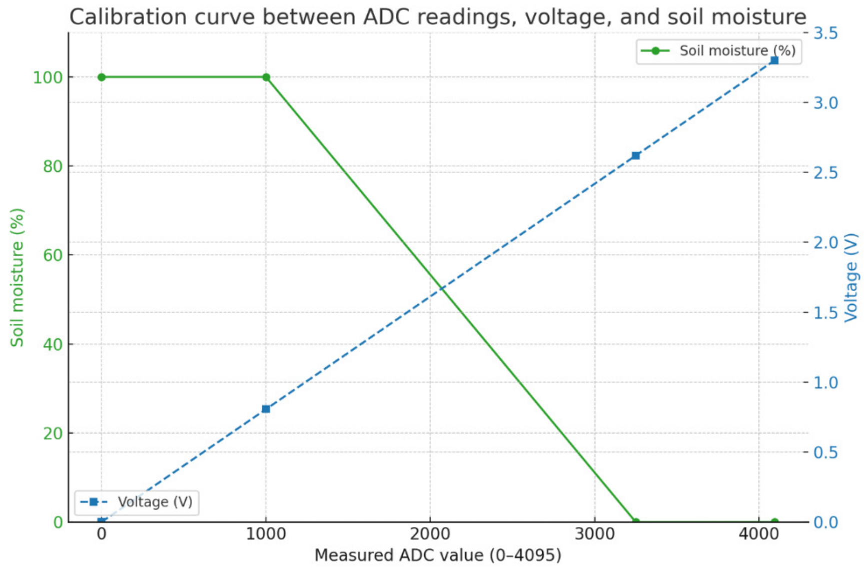

Fig. 2. Graph of the measurements obtained from the capacitive soil moisture sensor.

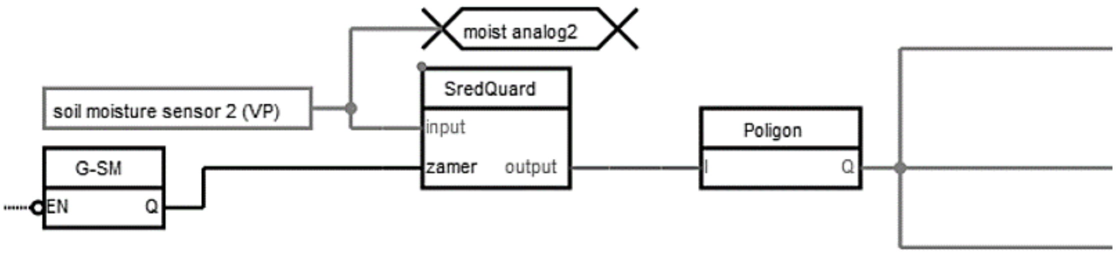

Fig. 3. Diagram illustrating the measurement pathway of the capacitive soil moisture sensor

mode. In the automatic mode, the measured soil moisture value is compared to a predefined threshold using a Comparator, with the input signal passing through a stabilization block to prevent spurious triggers. Upon reaching the set condition, a One-Shot timer (TON) activates the water pump for a fixed duration determined by the operator. At the end of the irrigation cycle, a Lockout timer (TOF) is engaged, introducing a mandatory delay before reactivation to prevent the sensor from immediately detecting dry soil and re-initiating irrigation, which could otherwise lead to undesired cyclic operation (Fig. 4).

The second control mode of the irrigation system is implemented via a weekly timer. This mode is realized using a Real-Time Clock (RTC) module with independent power supply, allowing the configuration of specific days and times for initiating irrigation cycles. Each day of the week is represented by a logical block that provides an enabling signal when the current date matches. Combined with the selected hour and minutes, this generates the condition for pump activation. The duration of irrigation is set through a separate parameter (watering time), ensuring that the pump remains active only for

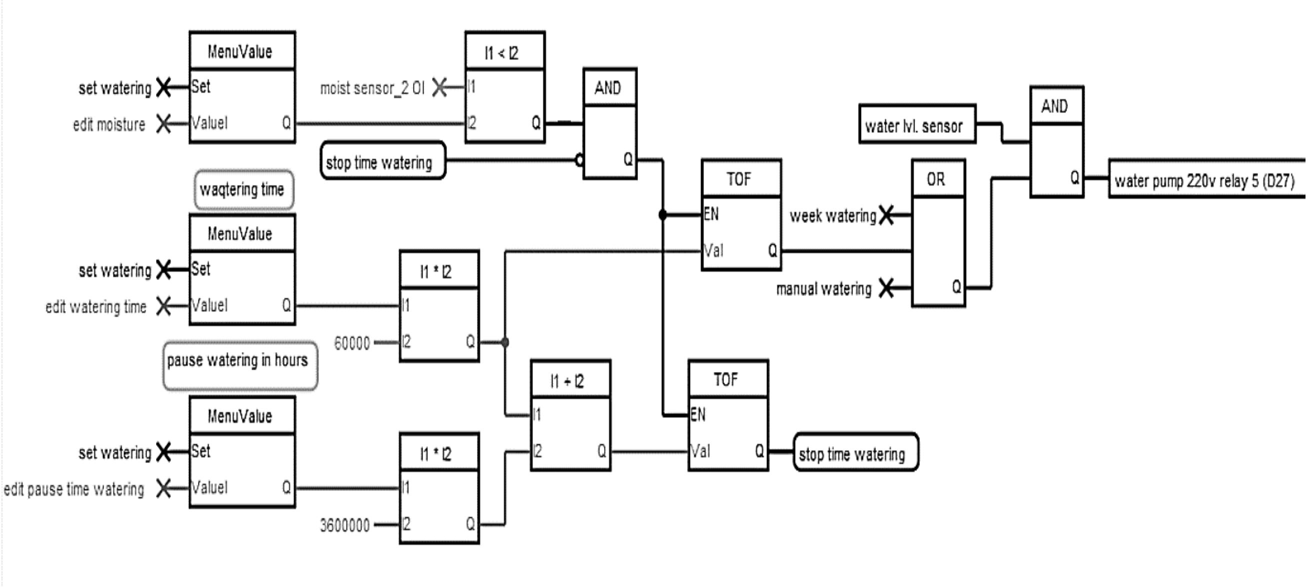

Fig. 4. Logic diagram of the automatic irrigation system.

the predefined interval. For the protection of the irrigation system, a capacitive non-contact liquid level sensor is integrated. This sensor detects changes in the capacitance of the surrounding medium associated with the solution level. When the liquid level in the tank falls below a preset minimum, the sensor triggers a warning signal, preventing the initiation of irrigation and thereby protecting the pump from potential damage.

Lighting control system

The construction of greenhouses incorporating various types of artificial lighting has become increasingly common [6]. In the developed system, the lighting is controlled via a Real-Time Clock (RTC) module. The start time and duration of the lighting cycle are predefined, enabling the program to automatically calculate the end time of each cycle. Thanks to its independent power supply, the RTC module ensures accurate timekeeping and allows the restoration of the lighting cycle after power interruptions. Upon power restoration, the cycle continues according to real time, maintaining synchronization. This control enables precise adjustment of light according to plant requirements, minimizing unnecessary operator intervention and ensuring system stability.

Time synchronization system

The Real-Time Clock (RTC) module is an integrated component that provides precise time tracking, independent of power interruptions. It plays a central role in system management by ensuring accurate control of lighting photoperiods and irrigation time intervals. The system also incorporates a function for tracking the stages of vegetative growth according to the week of development of a given crop. This capability enables dynamic adjustment of light exposure and nutrient delivery in accordance with the plant's growth phase.

Actuator control

The system controls actuators, including fans, lighting, and the irrigation system, through electromagnetic power relays. These relays employ galvanic isolation between the control coil (5 V DC) and the switching contacts, ensuring safety and protection of the low-voltage electronics. Their switching specifications allow handling currents up to 10 A at 220 V.

Software environment

The programming of all system functionalities was implemented using FLProg, a block-oriented programming platform based on functional logic blocks. This environment enables visual design of automation algorithms, providing clarity, ease of modification, and seamless integration of prebuilt modules for sensor and actuator control. Additionally, FLProg allows the creation of custom blocks, which can be adapted and configured to meet the specific requirements of each project.

Remote monitoring and control

Remote monitoring provides convenience for real-time observation and control of the systems [7]. For the development of a mobile control application, the RemoteXY software platform was employed. It offers prebuilt graphical components such as buttons, sliders, switches, indicators, and display fields, which can be arranged through a visual editor. The generated code is directly integrated into FLProg, establishing bidirectional communication via Wi-Fi. The platform supports real-time data exchange, transmission of control commands, and visualization of sensor readings (Fig. 5).

Technical components

The implementation of the project utilized the following technical components:

- ESP32 microcontroller based on the Arduino platform, supporting Wi-Fi and Bluetooth connectivity;

- sht20 digital sensor for measuring ambient temperature and humidity;

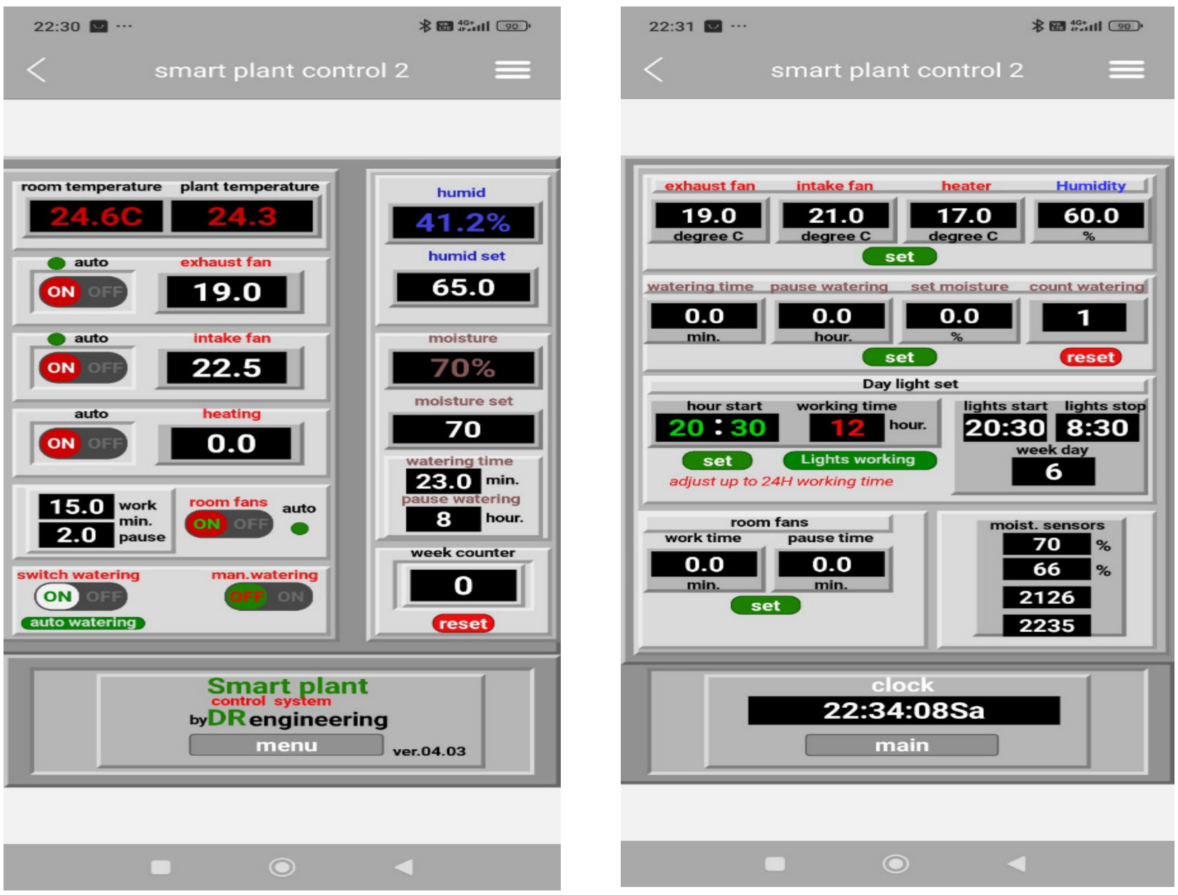

Fig. 5. User interface of the developed mobile application.

- capacitive soil moisture sensor (v2) for monitoring soil water content;
- electromechanical relays for controlling actuators, driven by the microcontroller;
- real-time clock (rtc) module to manage lighting schedules and system timing;
- programming environment – flprog, block-based development of control algorithms;
- remote monitoring via wi-fi communication with a custom mobile application developed using the remotexy platform;
- 4-line lcd display for visualizing real-time system measurements.

RESULTS AND DISCISSION

Practical implementation of the IoT system for monitoring and control

Fig. 6 illustrates the electrical schematic of the developed system, describing its hardware configuration. At its core lies the ESP32 microcontroller, interfaced with the SHT20 sensor module for measuring air temperature and relative humidity, as well as a capacitive soil moisture sensor. Power supply is provided by the HLK-PM01 AC-DC module, which converts the mains voltage of 230 V AC into a stabilized 5 V DC output. For safety and reliable operation, two fuses are implemented: a 10 A main fuse protecting the high-voltage circuit, and a 2 A secondary fuse securing the low-voltage control section. Accurate time synchronization is ensured by the DS3231 RTC module with independent power backup. Control of the actuators (exhaust and intake fans, water pump, and lighting) is achieved through four relay channels with galvanic isolation. The human–machine interface (HMI) is realized via a 16×4 LCD display and control buttons, allowing parameter configuration and real-time status monitoring. The system continuously monitors

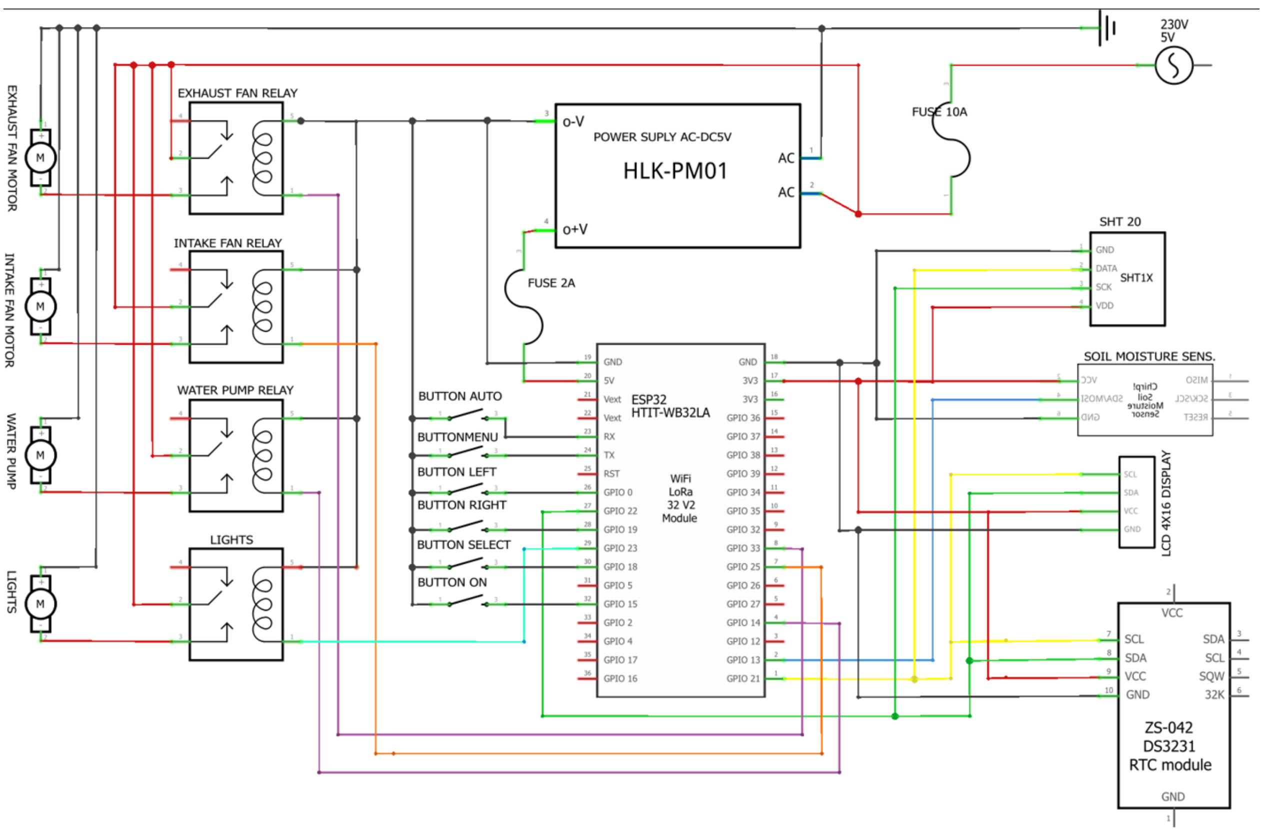

Fig. 6. Schematic diagram of the system connections.

climatic and soil parameters and provides real-time control of greenhouse processes.

The irrigation process was calibrated by a series of measurements compared with the readings of a reference device. Fig. 7 and 8 present the quantitative results of the soil moisture dynamics, including absorption during a controlled 15 min irrigation cycle and water evaporation rates for different soil types. The analysis of these relationships allowed the determination of the optimal duration of irrigation cycles and the appropriate intervals before subsequent measurements.

During a 24-hour monitoring of the greenhouse temperature profile, it was observed that at an outdoor temperature in the range of 30 - 31°C, the internal temperature without active ventilation increased to 33°C. When the ventilation system was activated, a decrease in temperature was recorded, with maximum values reaching 24 - 25°C, which represents an average decrease of approximately 7°C compared to the control case, and stabilization was achieved within 5 - 6 min. After deactivating the ventilation system, the internal temperature quickly approaches the external values.

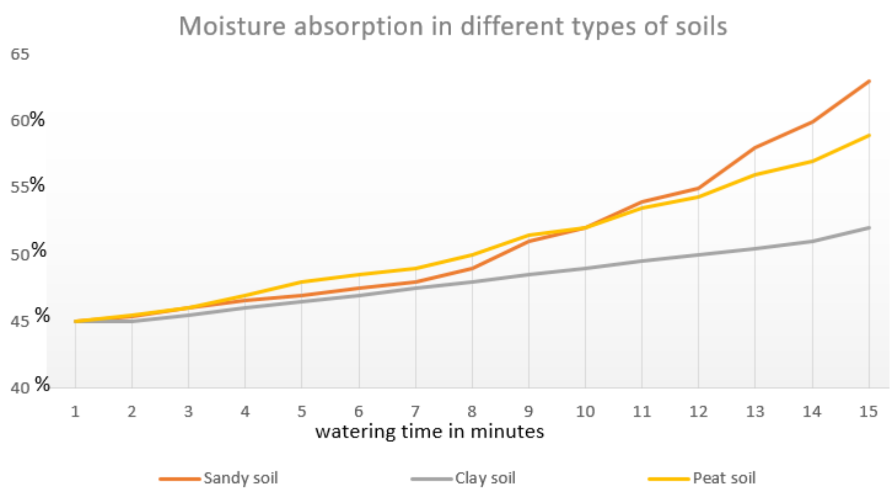

Fig. 7. Soil moisture absorption under irrigation.

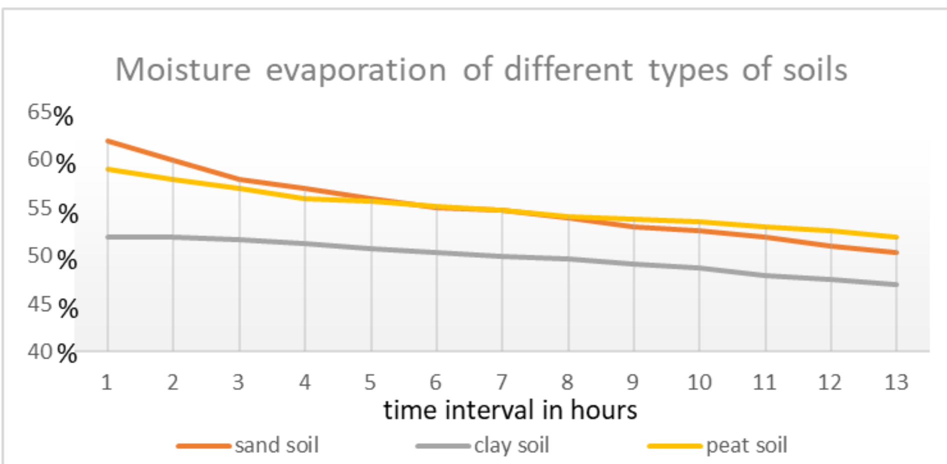

Fig. 8. Graphs defining evaporation of different types of soils.

A correlation was found between soil moisture and relative humidity in the greenhouse, with the latter increasing by approximately 15 % due to evaporation from the soil after irrigation. The operation of the ventilation system limited this fluctuation to a range of 55 - 58 %, while in the absence of active ventilation the values remained higher (~64 - 65 %).

The lighting control was tested within a predefined 12-hour cycle. The system correctly activated and deactivated the lighting devices at the scheduled intervals, and after a power outage its operation was restored in synchronization with real time without deviations.

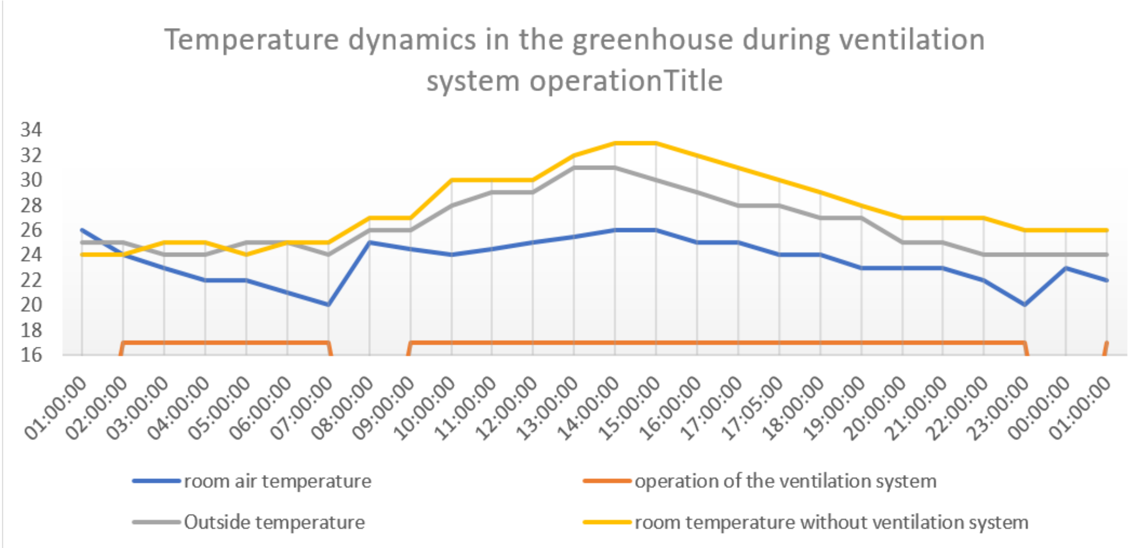

Fig. 9. Temperature dynamics in the greenhouse during ventilation system operation.

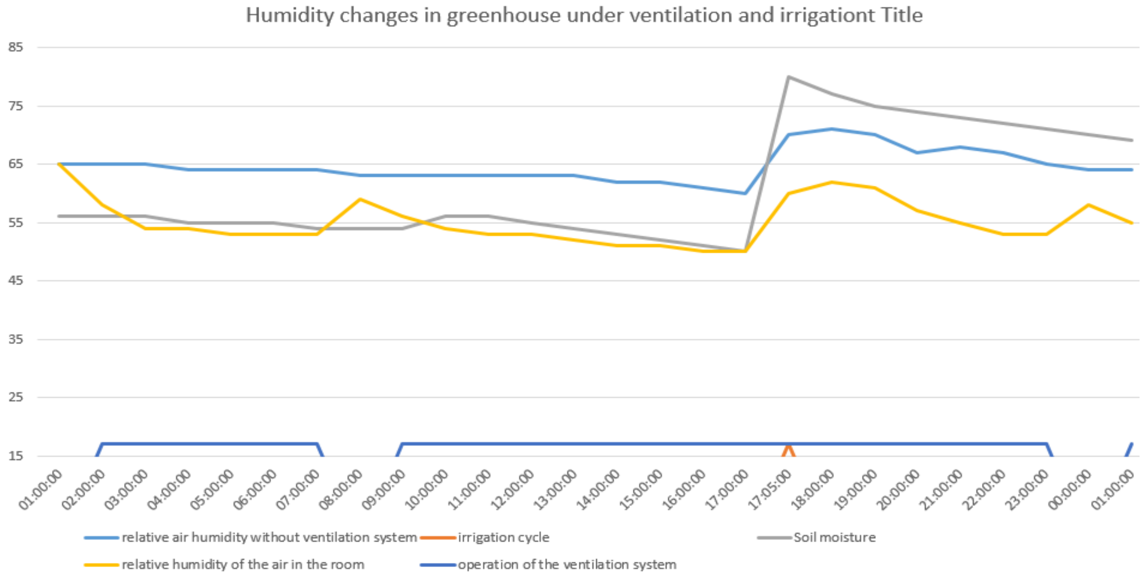

Fig. 10. Humidity changes in greenhouse under ventilation and irrigationt process.

Fig. 11. Prototype of the greenhouse control system controller.

CONCLUSIONS

The automation system demonstrates the potential of intelligent technologies for efficient management of resources and climatic conditions. Future enhancements include the integration of an EC sensor to measure nutrient concentrations in the soil, coupled with an automated dosing system for precise nutrient delivery at different stages of plant development [8]. Additionally, CO_2 sensors, automated nutrient dosing, and an interface with pre-configured settings for various crops are planned to further optimize cultivation conditions.

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