Design of Hydroponic System Plant Growing with Automatic Control

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Abstract**—** *Rapid urbanization and industrialization cause not only the reduction of agriculturally usable areas, but also a certain degree of modification of traditional cultivation practices. Cultivation of plants with the use of new technologies, characterized by the absence of land use, is experiencing significant development in areas of unconventional agriculture, primarily in areas with a lack of land or unsuitable soil quality. The article discusses the design of an island system for local year-round production of seasonal food using an alternative source of energy. The output is the design of your own hydroponic system with automatic control.*

Keywords— Hydroponics, Plants, Island System.

I. INTRODUCTION

Due to the constant increase in the number of people on our planet, the need for food and water is a fundamental problem for humanity. Another serious problem is the uncontrollable pollution of the planet and the associated loss of quality agricultural land. In many areas of the Earth there is a shortage of drinking water or environment unsuitable for growing plants. For this reason, hydroponic systems can provide a suitable environment for growing food while managing natural resources efficiently. The first large-scale experiments using hydroponic cultivation come from German botanists from the second half of the 19th century. One of the first successes of hydroponics occurred on Wake Island, a rocky atoll in the Pacific Ocean used as a refuelling stop for Pan American Airlines. Hydroponics was used there in the 1930s to grow vegetables for passengers. This method of cultivation was a necessity on Wake Island because there was no suitable land for growing the desired types of plants and the transportation of fresh vegetables by air was prohibitively expensive. In recent decades, NASA has conducted extensive hydroponic research on its Controlled Ecological Life Support System (CELSS). This research, mimicking the Martian environment, uses LED lighting to grow in a different colour spectrum with much less heat.

II. HYDROPONIC SYSTEMS

Hydroponics is one of the most modern methods of growing plants indoors. A characteristic feature of this method is growing plants in a nutrient medium without soil (Fig. 1). Hydroponic cultivation ensures optimal, almost natural conditions for growth and development, a certain degree of protection against diseases and at the same time a hygienic environment for plants, as the soil represents a potential source of various diseases, parasites and parasitic plants.

According to the distribution of the nutrient solution, hydroponic systems can be divided into closed and open. The closed system is characterized by feeding the nutrient solution to the plants in specially constructed cultivation troughs. The main advantage of this system is that the solution circulates and is fed back to the plants, which increases the extraction of the nutrients necessary for growth contained in the nutrient solution. Conversely, the primary disadvantage of nutrient solution recirculation can be the transmission of root diseases, which, however, poses a minimal risk under indoor conditions. The division of hydroponic systems according to the substrate and according to the environment that will be created around the root system is most often used. From this point of view, we distinguish between water, substrate and air cultures. Aquatic cultures have a closed circuit of nutrient solution distribution, plant roots are directly surrounded by it. A significant advance in the application of water cultures is the NFT (Nutrient Film Technique) system (Fig. 2), where the nutrient solution continuously flows through the bottom of the growing container, washes the roots in a thin layer (1-2 cm) and then returns to the storage tank.

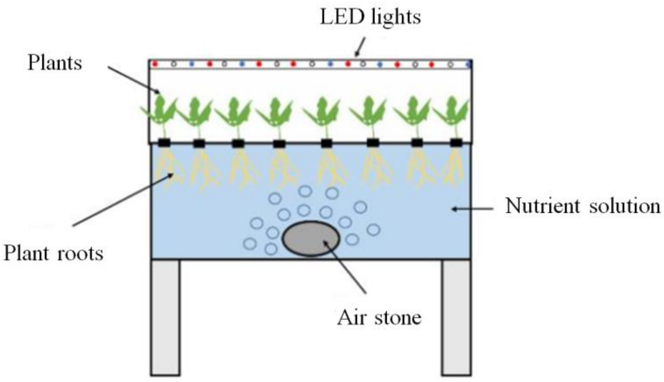

FIGURE 1: Hydroponics [1]

Plants have enough air. The second important system based on water culture is the DFT (Deep Flow Technique) system (Fig. 3), which is characterized by growing plants floating or hanging on supports (rafts, boards, panels) in containers filled with a nutrient solution.

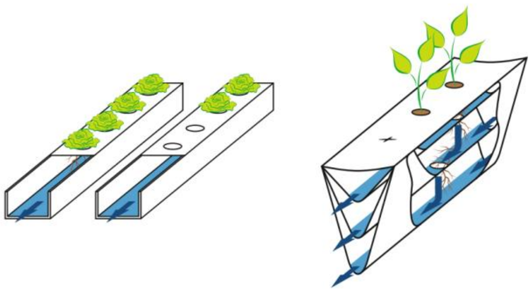

FIGURE 2: NFT system: single-layer trough (left), multi-layer trough (right)

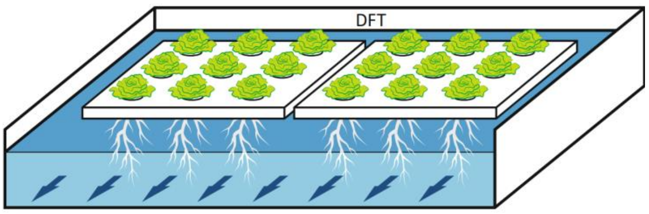

FIGURE 3: DFT system

Air culture, or aeroponics (Fig.4) is a soilless technology, which is characterized by the placement of plant roots in a closed device, while they are moistened with a nutrient solution at short intervals or continuously using a spray nozzle, which is placed under the plant root. In the aeroponic system, the plant grows in the air with the help of artificial support. Substrate culture is mostly used in interiors. Crops are grown in a solid, indoor non-inert medium instead of soil or water. As a medium for root systems, it uses substrates that are inert to chemicals, plant activity and microbial activity (e.g. inorganic substrates: coarser siliceous sand, inert volcanic tuffs, perlite, zeolite, gravel, stone wool, pumice, sepiolite, expanded clay, organic substrates: peat, conifer bark, wood chips). An effective substrate material must have a physical structure that creates an appropriate balance of air and water for healthy root development.

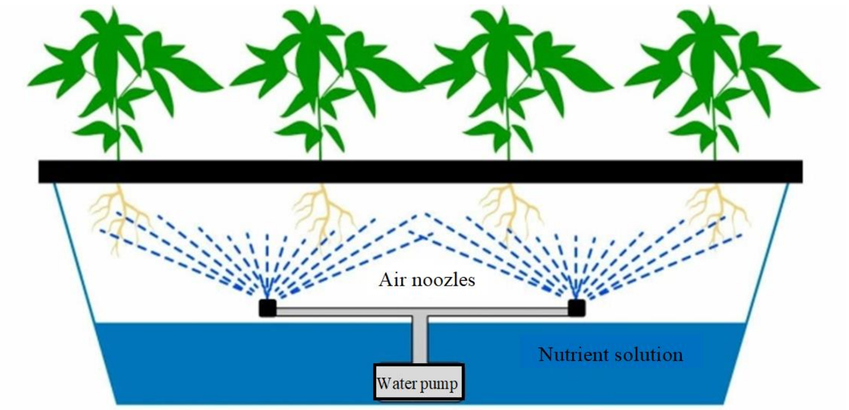

FIGURE 4: Air culture

Many plants, various crops and vegetables can be grown using hydroponic systems. The taste, nutritional value of the final products and their quality are generally higher compared to conventional soil cultivation. Experimental findings point to the possibility of successfully growing leafy vegetables (spinach, lettuce, parsley, celery, etc.) using hydroponics.

III. DESIGN OF AN ISLAND SYSTEM WITH THE POSSIBILITY OF YEAR-ROUND CULTIVATION OF SELECTED CROP TYPES

The implementation and operation of the island system for local year-round production of seasonal food is directly dependent on several aspects. It is possible to include the selected type of cultivated crop, its nutritional and light requirements, the need to maintain a suitable interior temperature, etc. When designing the island system, the NFT hydroponic system was chosen. The proposed system consists of the following components: growing unit, hydroponic system components (tanks, pumps, hoses, growing grids, air stones, etc.), growing medium, nutrient solution, ventilation system, temperature management system, software-hardware management equipment systems, pH and EC (electrical conductivity) meters, additional grow lights (LED, high-pressure sodium, etc.), backup source based on LiFePO4 battery pack, photovoltaic panels.

A shipping container 20 with internal dimensions of 5910x2345x2690 mm was designed as a growing unit. The container was insulated from the inside with glass wool and OSB boards. A container with a volume of 100 l was chosen for storing and supplying the plants with nutrient solution, which was placed in the corner of the container. Inside the container there is an air stone (diameter 150 mm and thickness 18 mm), which serves to aerate the nutrient solution, and thus ensures the distribution of oxygen to the cultivated plants. It is connected to a compressor pumping air from inside the container to bring it to the storage tank. The air stone divides the air flow into microbubbles, from which oxygen dissolves more easily in the water. The distribution of the nutrient solution by the hydroponic system is provided by a circulating pump (power 0.071 kW, maximum flow 55 $l \cdot min^{-1}$). Part of the designed system is also a hybrid air conditioning unit serving to reduce the system's energy requirements and ensure financial efficiency. Part of the designed system is also a hybrid air conditioning unit serving to reduce the system's energy requirements and ensure financial efficiency. To ensure the independent operation of the hydroponic system in the form of an island operation, photovoltaic panels (18 pcs., each with a maximum power of 500W) were chosen, which ensure the operation of the entire system and at the same time serve to recharge the batteries. The proposed accumulators are supposed to ensure the coverage of the energy requirements of the island system even when the photovoltaic panels do not supply the required electrical power. The hydroponic system was made of PVC pipes, where mesh cups were inserted into the drilled holes. Holes for supply and drain hoses were created in the PVC pipes. The pipe system was placed on a stand that considered the appropriate spacing of the pipes connected by means of clamps depending on the plant being grown. An LED strip with adjustable colour and intensity of radiation was chosen as a substitute for natural light for growing plants. An EC meter was used to measure conductivity in the nutrient solution, and a pH meter was used to measure its alkalinity. Mineral wool was used as a growing medium. In the given island system, the cultivation of leafy vegetables is ensured with the help of hydroponics.

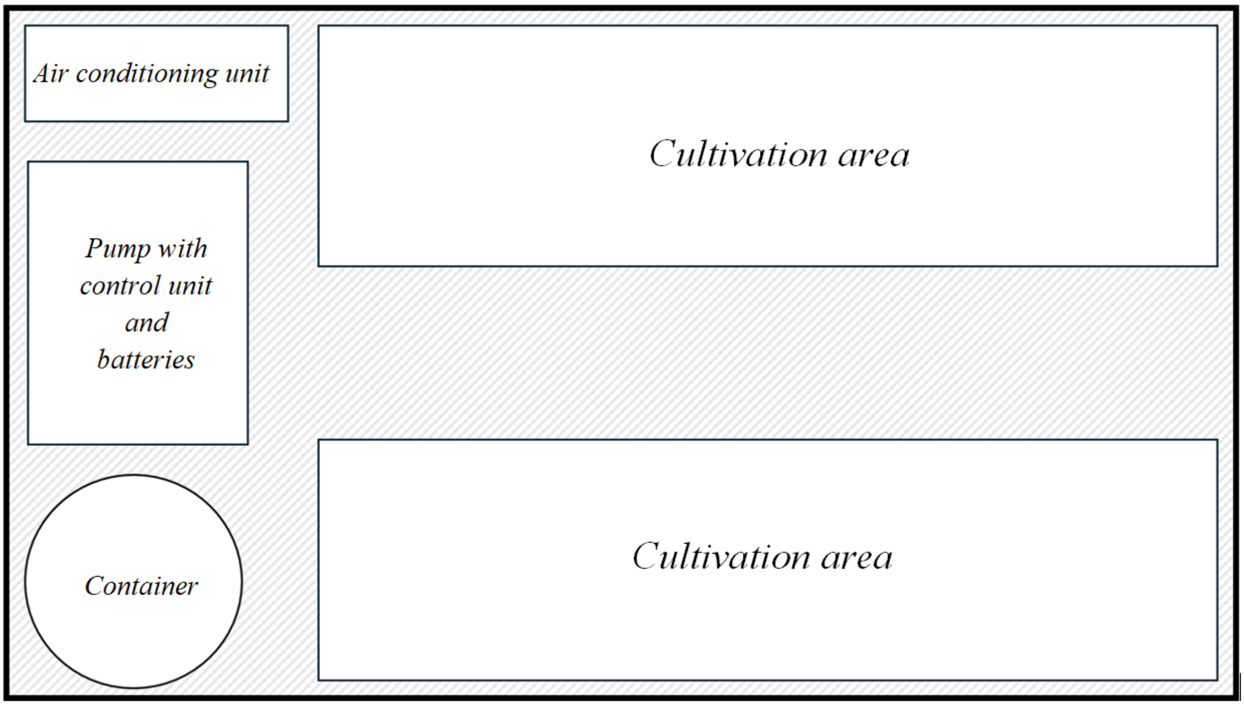

FIGURE 5: Scheme of the shipping container equipment

To ensure appropriate management of temperature, amount of nutrients and lighting intensity according to the requirements of individual plant species and according to their level of development, a Raspberry Pi 4 microcomputer was chosen. The use of microcomputers ensures a reduction in energy requirements for the control unit and at the same time enables remote access to ensure regular monitoring required parameters without the need for physical presence. Sensors monitoring the basic values of the nutrient solution using EC and pH probes, the temperature of the solution, the flow of the solution through the cultivation device and the possible occurrence of unwanted algae using optical sensors are connected to the microcomputer system. The system also monitors the level of the nutrient solution in the container and, in the event of a sharp drop, ensures the closure of the entire system and reports a malfunction. To add nutrients to the main tank, a tank with nutrients is connected to it using a small pump, which is controlled by a microcomputer, and in the event of a decrease in nutrients in the main tank, they are automatically replenished. Sensing the amount of nutrients in the main container was chosen with regard to easier controllability of their amount. The system also monitors the amount of nutrients at the exit from the growing part for the analysis of the consumption of the nutrient medium in individual parts of the vegetation cycle of the cultivated plants.

Fig. 6 shows the resulting design of an island system for local year-round production of seasonal food capable of producing approx. 1680 pieces of leafy vegetables.

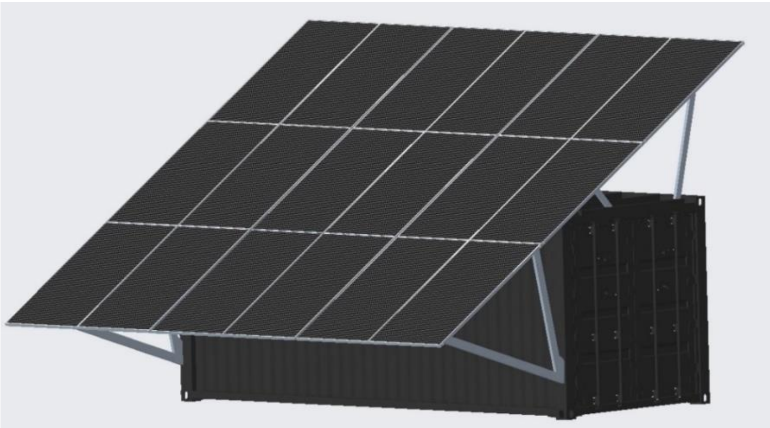

FIGURE 6: Container model

The hydroponic growing system requires the maintenance of stable operating conditions during the entire working cycle regardless of external conditions. To ensure the required operational parameters, it was necessary to propose the necessary structural modifications, which include the insulation of the transport container, the installation of the energy system and temperature management. The temperature management system was designed with heat gains and losses in mind throughout the year. With the changing external temperature, there is also a change in the demands on temperature management, primarily on its performance, with the aim of maintaining an interior temperature of 25 °C. Performance requirements, whether for heating or cooling throughout the year, are shown in table 1.

TABLE 1
PERFORMANCE REQUIREMENTS OF A HYDROPONIC SYSTEM

Outside temperature (°C)	Required heat output to maintain stable internal conditions (25°C) (kW)	Intensity of air exchange in the container (h^{-1})	Evaluation of performance requirements
-30	5.88	0.5	Heat up
-6	3.49	1	Heat up
-3	3.15	1	Heat up
5	2.24	1	Heat up
8.5	1.85	1	Heat up
15	1.11	1	Heat up
18.5	0.72	1	Heat up
40	1.63	0.5	Cool down

The required heat output for maintaining stable internal conditions was calculated according to the STN EN 128 31-1 standard for the Košice location.

For the need to cover the energy self-sufficiency of thermal management and associated systems for hydroponic cultivation, a photovoltaic system installed on a steel structure placed on a container according to fig. 6. The angle of inclination of the panels is 30°, while their secondary function is the screening of the container itself. Shading the container ensures protection against overheating due to direct sunlight, which would increase the energy requirements for cooling during the hottest months of the year. The total installed power of the photovoltaic system is 9 kW. The hydroponic system is in Košice, which is essential information for considering the daylight hours to calculate the amount of energy produced by the photovoltaic panels. With 14 hours of sunlight, the system can produce 126 kWh of electricity through 18 photovoltaic panels.

Thermal management consumption is defined as variable, while hydroponic growing system consumption is constant. Instability in the amount of incident solar radiation, primarily during the winter period, has the task of compensating the designed battery systems, consisting of LiFePO4 batteries. They use the free space in the shipping container, where it is not possible to directly install any technology or cultivation equipment. The chosen number of batteries is 33, which represents storage for 84.48 kW of electricity. The water contained in the hydroponic system also serves as a temperature stabilization medium. The total volume of water exceeds 195 l, which creates a storage source of thermal energy. It serves to stabilize the internal operating conditions in the transport container for hydroponic crop cultivation. In case of deterioration of external conditions, thanks to microcomputer control, it is possible to adjust the energy consumption of the entire system in such a way that cultivated plants are protected for a longer period from the effects of the external cold environment. Such interventions include limiting the exchange of air with the external environment, reducing the temperature in the growing environment to 10 °C, which will decrease the energy requirements for heating, as well as reducing the exposure time of the plants and the operating time of the circulation pumps. The main reason for the deterioration of external conditions in winter is the covering of photovoltaic panels with a layer of snow or frost, or a long-term reduced supply of solar radiation caused by unfavourable meteorological conditions.

IV. CONCLUSION

The biggest benefit of hydroponics is growing plants without using soil. Thanks to this, plants can be grown even in an otherwise unfavourable environment, many times even with extreme conditions. From the point of view of huge saving of area, hydroponics can be used even in urban areas for vertical cultivation. The proposed modular island system represents a self-sufficient local year-round production of seasonal food, as it uses photovoltaic panels with a set of appropriately selected batteries to ensure the necessary operating conditions. The modularity of the container enables the system's exploitability to be increased by increasing the number of connected units without the need for drastic intervention in individual modules. The primary purpose of the article is an attempt to describe the possibilities of applying container plant growing systems even in areas of urban urbanization without the need for significant interventions in the environment. The article is the initial phase of research into the applicability of hydroponic growing systems in unused industrial and commercial spaces within the territory of the Slovak Republic and the surrounding area.

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