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DESIGN AND DEVELOPMENT OF AN INTERNET OF THINGS (IOT) BASED REAL TIME MONITORING AND CONTROL SYSTEM FOR SMART INDOOR HYDROPONIC VERTICAL FARMING SYSTEM WITH ESP32 AND ADAFRUIT IO

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Abstract:

Vertical farming is an unconventional method of agriculture where crops are grown in a vertically stacked manner in a controlled environment either in indoor or outdoor setup. Hydroponic is a concept where crops are grown in water filled with mineral nutrients instead of soil. Hydroponic vertical farming system thus represents a farming fashion where crops are grown vertically, and their roots submerged in nutrient-rich water. In this paper, we have implemented a hydroponic vertical farming system and utilized the concept of Internet-of-Things (IoT) to monitor and control the environmental parameters in real time on a dashboard with ESP32, MQTT broker and Adafruit IO. The developed system acquires real-time environmental values such as temperature, humidity, nutrient concentration in water, level of water and nutrient supply, battery voltage, and power consumption. The challenges and future suggestions are also described in this paper.

Keywords:

Vertical Farming, Internet of Things (IoT), Hydroponics, Real-Time Monitoring, Intelligent Systems

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Introduction

The increase rate of the earth's population is increasing at an alarming rate day by day, and by the year 2050, the population might reach nine billion (Arora, 2019; Loboguerrero et al., 2019) which will produce crises in multiple directions. The ever-increasing population is demanding more food production, and at the same time, the amount of arable land area is decreasing due to the accommodation requirement for this increasing number of populations. Along with population growth, climate change is also affecting the agricultural sector. According to the World Food Programme's (WFP) report for 2018, the crop growth rate per unit land area has reduced significantly. The hunger crisis has become a burning issue all over the world. To meet the increasing demand for food, it is essential to increase the amount of food production. Orthodox methods of agriculture are now struggling to meet demand because of reduced arable land and the impact of climate change (Benke & Tomkins, 2017). Vertical farming has grown in popularity in terms of applications, ranging from industrially driven vertical farming to home-based vertical farming and even vertical farming in or near restaurants for consumption by the restaurants.

Vertical farming is a concept in agriculture in which crops are grown in vertically stacked layers (Faber et al., 2020; Kalantari et al., 2020; SharathKumar et al., 2020; Van Gerrewey et al., 2021) instead of growing crops in a large land area. The advantage of farming in this fashion is that more crops can be produced per unit land area compared to the traditional method of farming. This method is also known as "controlled environment agriculture" as the crops are grown in an environment where certain atmospheric aspects such as temperature, humidity, intensity of light, water and nutrition supply, etc. are controlled in a systematic manner. The vertical farming technology minimizes supply waste since water and nutrition parameters are efficiently distributed.

Since vertical farming systems are developed in a controlled environment, they can be produced and installed anywhere around the globe, including outdoors and indoors regardless of the surrounding weather conditions. Furthermore, crops grown in vertical farms are free from pests and insects which also contributes to a higher yield and lower maintenance cost. Vertical farms are generally soilless systems. There are three types of vertical farming systems: hydroponic, aeroponic, and aquaponic. The most popular system is hydroponic vertical farming (Khan et al., 2020; Son et al., 2020). Hydroponics is a type of vertical farming system in which crops are grown using mineral nutrient solutions dissolved in water instead of soil. As a hydroponic system does not require soil and the plants get the necessary nutrition from the water, it is possible to grow any type of crop anywhere around the globe by controlling the environment, which is impossible in many soil-based cases as the soil in all places does not contain all types of nutrients. Hydroponic farming has gained much popularity in recent years because of its unmatched advantages.

Vertical farming systems utilize the concept of the Internet of Things (IoT) (Habib et al., 2022; Md Saad et al., 2021; Rahimi et al., 2020) to monitor and control the environment continuously. Sensors and actuators are installed inside the system, through which it is possible to obtain real-time measurements of the system and control the system's parameters in real time. Chowdhury (Chowdhury et al., 2020) developed a system for an IoT-based indoor hydroponic vertical farm in Qatar to monitor the farm's system in real time. However, there is no real-time automated control from the web server.

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Saad (Khan et al., 2020) has listed the recent trends in vertical farming systems. Ruscio (Francesco Ruscio et al., 2019) also developed an IoT-based hydroponic vertical farming system to show the sensors' values in the dashboard. But they have not provided any power consumption information. Also, their system does not have any automated control from the web server. Chuah (Chuah et al., 2019) developed a monitoring and control system for a vertical farming module on an Android app. However, there is also no automated control; the only way to control the light and pump is by interacting manually with the app. Also, there is no level indicator for the water and other chemicals present in the system, which may show false operations when actions are taken from the mobile app.

Haris (Haris et al., 2019) has developed an indoor vertical farming system with monitoring and automated control features from the web server. However, they have interfaced a few sensors with the controller unit via Bluetooth Low Energy (BLE), which might face interference with nearby Bluetooth or Wi-Fi devices, causing incorrect values of data or missing data. Bhowmick (Bhowmick et al., 2019) has developed an IoT-based system for monitoring their vertical farming module, but they also do not have any real-time automated control from the web server. Bakhtar (Bakhtar et al., 2018) developed a system to monitor a few sensors' values in the web server. However, they do not have any pump control in their system. The user needs to monitor the sensors' status from the web panel and then take any necessary action. Chin (Chin & Audah, 2017) has an actuator control system from the web panel, but it is not automated. Rather, the user needs to analyse the sensors' values and control the actuators, such as lights and pumps, accordingly.

In this paper, we present the development of an IoT based hydroponic indoor vertical farming module. The developed module acquires real-time environmental values (temperature, humidity, nutrient concentration in water, level of water and nutrient supply, battery voltage, and power consumption) and transmits the values to the Adafruit IO cloud, where the measurements of each parameter can be viewed in the dashboard. Adafruit IO also offers a database to store one month of data for the free users, and historical data can also be viewed in graphs for each parameter. Logical condition checking is also offered by Adafruit IO, and using that, the controls of light, water, and nutrient pumps have been automated. An alert email is also sent from the Adafruit IO to the user to notify them of any critical condition that has occurred in the system.

The paper is organised as follows: The next section provides a brief overview of the architecture of vertical farming systems, including sensors, microcontrollers, and an IoT platform. Then, the following Section covers the real-time monitoring of a smart indoor hydroponic vertical farming system, the discussion, and future work recommendations. The last Section gives the conclusion of the proposed study.

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Vertical Farming System Architecture

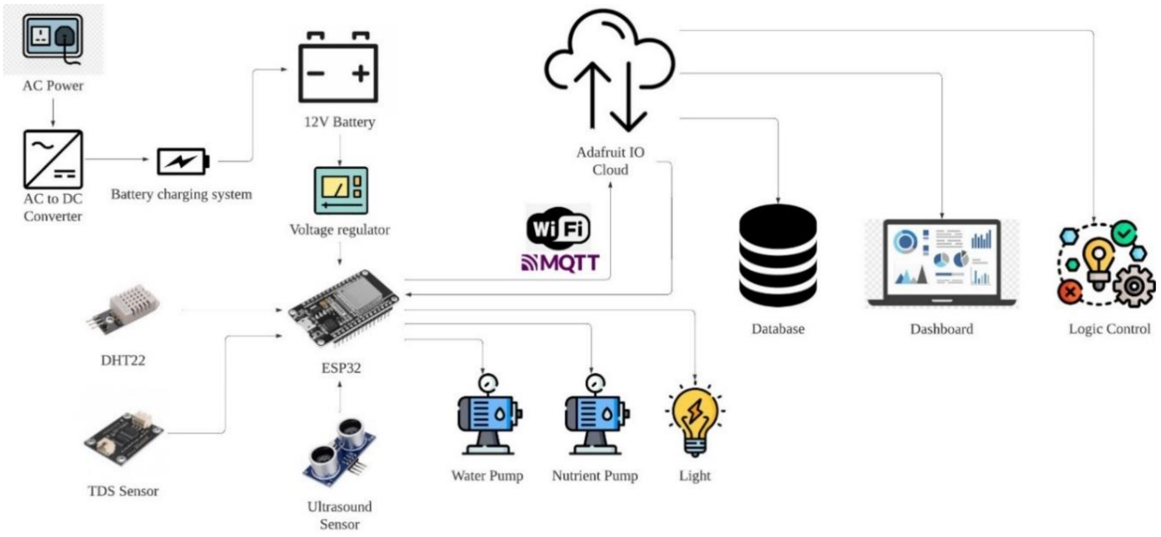

Figure 1: System Architecture of The Vertical Farming Module

Figure 1 represents the proposed system architecture of the vertical farming module. The primary controller for the system is an ESP32 microcontroller development board. The reason for choosing the ESP32 is that this microcontroller comes with built-in support for Wi-Fi and the MQTT protocol; hence, the programming is easier compared to other microcontrollers. The ESP32 is responsible for interfacing with the sensors and the cloud dashboard.

The power supply for the system is taken from the AC power outlet and transferred to a 12 V DC battery through an AC-DC converter and charging system. The 12V DC battery feeds the entire system through a 5V voltage regulator. The reason for installing a 12 V DC battery is to provide power to the system at times of blackouts and transportation so that the plants' environment does not get hampered. The DHT22, TDS sensor, and two ultrasound sensors are all connected to the ESP32.

DHT22 is a digital temperature and humidity sensor. It measures the temperature and humidity inside the system. It is connected to the ESP32 through a GPIO pin, and it transmits the data using the One Line Communication protocol. TDS is an abbreviation for Total Dissolved Solids in a liquid. The TDS sensor measures the amount of organic and inorganic substances dissolved in the water and expresses the output as parts per million (ppm). This sensor is used to measure the nutrient concentration in our hydroponic system. The sensor provides an analogue output, which is connected to the ESP32 through an ADC input. The value of the sensor's output is dependent on the temperature. The output is calculated using the GravityTDS library with temperature compensation. The output (ppm) is then converted to a percentage value according to the amount of water present in the tank for easy understanding by the user.

The ultrasound sensor is a sensor that houses an ultrasound transmitter and receiver. This sensor is used in our system to measure the amount of water that is present in the tank. We

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have used two: one for measuring the water in the water tank and another for measuring the nutrients present in the nutrient tank. The ultrasound sensors are connected to the ESP32 through GPIO pins. For measuring the volume of water present in the tank, we first measure the length of the empty tank by placing the sensor on the top surface of the tank. Then, after the liquid is poured inside the tank, we take measurements again, and this time we get the length between the sensor and the water surface as the sound wave reflects from the water surface to the ultrasound receiver. From the difference between the full length of the tank and the vacant space in the tank, we measure the amount of liquid that is present in the tank.

There are three actuator systems connected to the ESP32: two water pumps, one for pumping water into the system from the water tank and another for pumping nutrients into the water tank from the nutrient tank; and a lighting system. The water pumps and lights get their power from the 12V DC supply, and the ESP32 controls the pumps and lights by sending logic signals through the GPIO pin to their respective driver circuits. The ESP32 connects to the pre-configured Wi-Fi and then connects to the Adafruit MQTT broker. The MQTT broker, port, and credentials are programmed into the ESP32. The topics for MQTT messages for each sensor and actuator and the dashboard have been created first in Adafruit IO. The ESP32 keeps measuring the sensors' values continuously and publishes those values to the MQTT broker every five minutes.

Adafruit IO offers attractive features to everyone, free or paid. Features come with restrictions for free users. For example, only ten feeds can be accessed at a time for a project, and the database will store one month of data for free users. Adafruit IO also offers an interactive dashboard. Logic operations were created in Adafruit IO to control the pumps automatically based on the programmed threshold values. The ESP32 subscribes to the topics for pump control, and whenever there is a command sent from Adafruit IO, the ESP32 turns on or off the pumps, thus reducing human intervention.

Real Time Monitoring of Smart Indoor Hydroponic Vertical Farming System

(a) Water Pump and Lights Status **(b) Light and Nutrient Status**

Figure 2: Dashboard Display for Real-Time Monitoring of Smart Indoor Hydroponic Vertical Farming System

Figure 2(a) and 2(b) shows the dashboard display where instantaneous values of each sensor and actuator can be seen. From Figure 2(a) only water pump and lights are on. The nutrient

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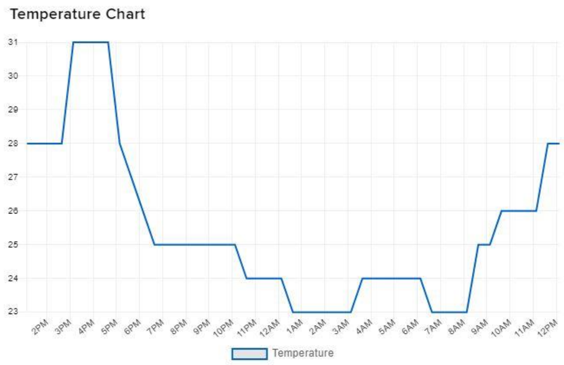
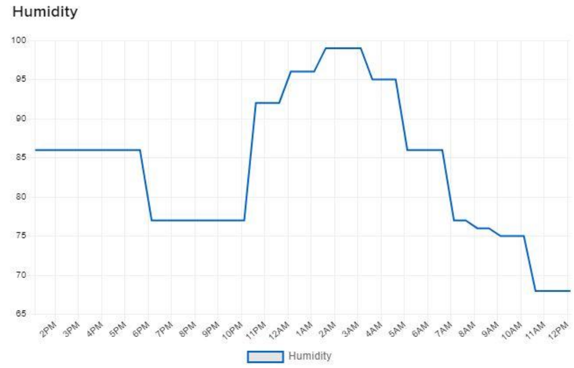
pump is kept off as the nutrient level is above the threshold value. When the nutrient level falls below the threshold value the nutrient pump is turned on automatically (Figure 2(b)).

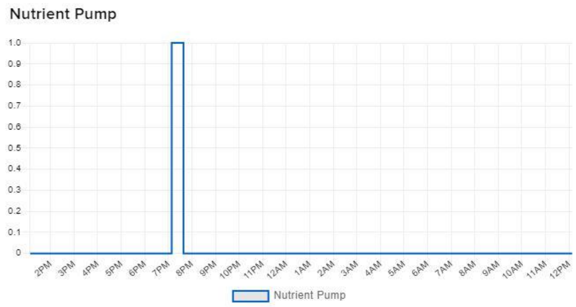


(a) Temperature

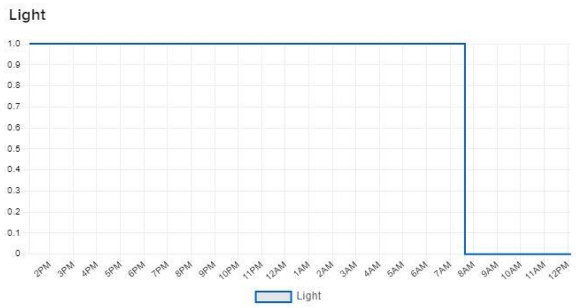


(b) Humidity

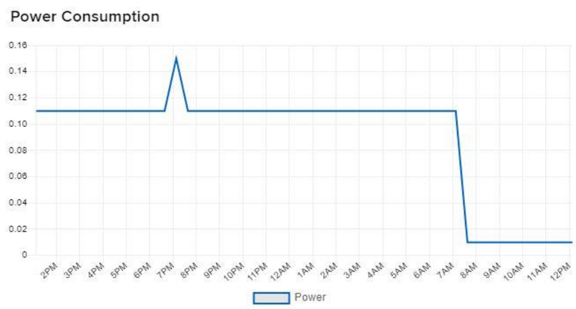
(c) Nutrient Level



(d) Nutrient Pump



(e) Light



(f) Power Consumption

Figure 3: Sensor Reading For (a) Temperature, (b) Humidity, (c) Nutrient Level, (d) Nutrient Pump, (e) Light and (f) Power Consumption for 24 Hours

Figures 3(a) to 3(f) represent the historical graphs for temperature, humidity, nutrient level, nutrient pump, light, and power consumption, respectively, over the past 24 hours. From Figures 3(c) and 3(d), it can be observed that the nutrient level fell below the threshold at 7 p.m., and at the same time, the nutrient pump was turned on automatically. At around 7:30 p.m., the nutrient level exceeded the threshold, and the pump shut down automatically. Figure

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3(f) depicts the power consumption as it relates to the activities. When only the lights were on (Figure 3(e)), the power consumption was about 0.11 kW. At 7 p.m., when the nutrient pump was turned on (Figure 3(d)), the power consumption rose to about 0.15 kW and again dropped to 0.11 kW when the nutrient pump was turned off at 7:30 p.m. When the lights were turned off at about 8 a.m. (Figure 3(e)), the power consumption dropped to about 0.01 kW at the same time. Figure 4 shows the physical setup of the system and the growth of the plants.

(a) Mechanical Setup **(b) Final Yield**

Figure 4: (a) Physical Setup of The System and The Growth of The Plants

Discussion and Future Work

From the experimental results, it is seen that the sensors are collecting the values of the parameters in real time and that the ESP32 is effortlessly in communication with the MQTT broker. The logics implemented in the broker are also working accordingly.

The limitations of the present system and some future suggestions are described in the following:

a) There are only logical operations performed by the broker. There are no analytical operations performed on the data. Machine learning-based data analytics can further enhance the effectiveness of the system.
b) There are only logical operations performed by the broker. There are no analytical operations performed on the data. Machine learning-based data analytics can further enhance the effectiveness of the system.

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c) The lights of the system are now operated in a scheduled manner. Inclusion of a light sensor and the requirement for light calculated by machine learning-based data analytics can produce optimised automated control of the lights.

Conclusion

In this paper, an IoT-based real-time monitoring and control system for an indoor vertical farming module has been presented. The system's controller has been implemented using an ESP32 microcontroller development board, and the dashboard has been hosted in Adafruit IO. Sensors to monitor the environmental parameters have been interfaced with the ESP32 board, and the ESP32 board is connected to Wi-Fi for communicating with the MQTT broker at Adafruit IO. Vertical farming is a prominent approach for meeting the increased demand for food across the globe, and when integrated with sensors, actuators, and the IoT, the productivity of this system can be increased even further.

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References

Arora, N. K. (2019). Impact of climate change on agriculture production and its sustainable solutions. *Environmental Sustainability 2019 2:2*, *2*(2), 95–96. https://doi.org/10.1007/S42398-019-00078-W

Bakhtar, N., Chhabria, V., Chougle, I., Vidhrani, H., & Hande, R. (2018). IoT based hydroponic farm. *Proceedings of the International Conference on Smart Systems and Inventive Technology, ICSSIT 2018*, 205–209. https://doi.org/10.1109/ICSSIT.2018.8748447

Benke, K., & Tomkins, B. (2017). Future food-production systems: vertical farming and controlled-environment agriculture. *Https://Doi.Org/10.1080/15487733.2017.1394054*, *13*(1), 13–26. https://doi.org/10.1080/15487733.2017.1394054

Bhowmick, S., Biswas, B., Biswas, M., Dey, A., Roy, S., & Sarkar, S. K. (2019). Application of IoT-Enabled Smart Agriculture in Vertical Farming. *Lecture Notes in Electrical Engineering*, *537*, 521–528. https://doi.org/10.1007/978-981-13-3450-4_56

Chin, Y. S., & Audah, L. (2017). Vertical farming monitoring system using the internet of things (IoT). *AIP Conference Proceedings*, *1883*. https://doi.org/10.1063/1.5002039

Chowdhury, M. E. H., Khandakar, A., Ahmed, S., Al-Khuzaei, F., Hamdalla, J., Haque, F., Reaz, M. B. I., Shafei, A. Al, & Al-Emadi, N. (2020). Design, construction and testing of iot based automated indoor vertical hydroponics farming test-bed in qatar. *Sensors (Switzerland)*, *20*(19), 1–24. https://doi.org/10.3390/S20195637

Chuah, Y. D., Lee, J. V., Tan, S. S., & Ng, C. K. (2019). Implementation of smart monitoring system in vertical farming. *IOP Conference Series: Earth and Environmental Science*, *268*(1), 012083. https://doi.org/10.1088/1755-1315/268/1/012083

Faber, M. J., Van Der Zwaag, K. M., Dos Santos, W. G. V., Rocha, H. R. D. O., Segatto, M. E. V., & Silva, J. A. L. (2020). A Theoretical and Experimental Evaluation on the

Journal of Information System and Technology Management
JISTM
EISSN: 0128-1666
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DOI: 10.35631/JISTM.728010
Performance of LoRa Technology. *IEEE Sensors Journal*, *20*(16), 9480–9489. https://doi.org/10.1109/JSEN.2020.2987776

Francesco Ruscio, Paolo Paoletti, Jens Thomas, Paul Myers, & Sebastiano Fichera. (2019). 10010845 (1). *International Journal of Agricultural and Biosystems Engineering*. https://publications.waset.org/10010845/low-cost-monitoring-system-for-hydroponic-urban-vertical-farms

Habib, K., Saad, M. H. M., Hussain, A., Sarker, M. R., & Alaghbari, K. A. (2022). An Aggregated Data Integration Approach to the Web and Cloud Platforms through a Modular REST-Based OPC UA Middleware. *Sensors 2022, Vol. 22, Page 1952*, *22*(5), 1952. https://doi.org/10.3390/S22051952

Haris, I., Fasching, A., Punzenberger, L., & Grosu, R. (2019). CPS/IoT Ecosystem: Indoor Vertical Farming System. *2019 IEEE 23rd International Symposium on Consumer Technologies (ISCT)*, 47–52. https://doi.org/10.1109/ISCE.2019.8900974

Kalantari, F., Nochian, A., Darkhani, F., & Asif, N. (2020). The Significance of Vertical Farming Concept in ensuring Food Security for High-Density Urban Areas. *Jurnal Kejuruteraan*, *32*(1), 105–111. https://doi.org/10.17576/jkukm-2020-32(1)-13

Khan, S., Purohit, A., & Vadsaria, N. (2020). Hydroponics: current and future state of the art in farming. *Journal of Plant Nutrition*, *44*(10), 1515–1538. https://doi.org/10.1080/01904167.2020.1860217

Loboguerrero, A. M., Campbell, B. M., Cooper, P. J. M., Hansen, J. W., Rosenstock, T., & Wollenberg, E. (2019). Food and Earth Systems: Priorities for Climate Change Adaptation and Mitigation for Agriculture and Food Systems. *Sustainability 2019, Vol. 11, Page 1372*, *11*(5), 1372. https://doi.org/10.3390/SU11051372

Saad, M. H. M., Akmar, M. H. S., Ahmad, A. S. S., Habib, K., Hussain, A., & Ayob, A. (2021). Design, Development Evaluation of A Lightweight IoT Platform for Engineering Scientific Applications. *2021 IEEE 12th Control and System Graduate Research Colloquium, ICSGRC 2021 - Proceedings*, 271–276. https://doi.org/10.1109/ICSGRC53186.2021.9515199

Rahimi, M. K. H., Md Saad, M. H., Mad Juhari, A. H., Sulaiman, M. K. A. M., & Hussain, A. (2020). A Secure Cloud Enabled Indoor Hydroponic System Via ThingsSentral IoT Platform. *2020 IEEE 8th Conference on Systems, Process and Control (ICSPC)*, 214–219. https://doi.org/10.1109/ICSPC50992.2020.9305792

SharathKumar, M., Heuvelink, E., & Marcelis, L. F. M. (2020). Vertical Farming: Moving from Genetic to Environmental Modification. *Trends in Plant Science*, *25*(8), 724–727. https://doi.org/10.1016/J.TPLANTS.2020.05.012

Son, J. E., Kim, H. J., & Ahn, T. I. (2020). Hydroponic systems. *Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production: Second Edition*, 273–283. https://doi.org/10.1016/B978-0-12-816691-8.00020-0

Van Gerrewey, T., Boon, N., & Geelen, D. (2021). Vertical Farming: The Only Way Is Up? *Agronomy 2022, Vol. 12, Page 2*, *12*(1), 2. https://doi.org/10.3390/AGRONOMY12010002