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Assessment of utilizing solar energy to enhance the performance of vertical aeroponic farm

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Abstract. The manuscript presents the significance of utilizing renewable energy in vertical aeroponic farming system. Components such as the tower garden, the solar panels, the water pump, and the control unit are integrated and designed to generate sufficient solar energy to power the system. The environmental conditions inside the chamber are optimized for plant growth, to maintain 18-24 °C temperature and relative humidity of 75-85 %. The paper also discusses the challenges, limitations, and future recommendations for improving the system. Finally, the paper provides some future recommendations for improving the design and performance of the solar powered vertical farm.

Introduction

Vertical farming (VF) is a process to produce food via utilizing vertical dimension for hydroponic growing of crops with indoor controlled-environment agriculture. Vertical gardens play a key role in tackling the ongoing challenges that modern cities encounters, due to a rapid growing in urban environment associated with the scarcity of water and the major growing in population, crises in food demand are emerged. Researchers predict about 25%-70% increasing in the crops needs by 2050 [1]. However, with the decrement in the availability of growing lands together with the worsen of climate condition, rises the demand of VF. The term "vertical farming" refers to the utilization of several vertical layers of crops planted within a warehouse to create an artificial growth environment that mimics horizontal farming.

Food costs remain augmented for several factors such as including population growing and food shortage. Although traditional Horizontal Farming HF are less expensive to maintain and build than greenhouses, such method still requires large landscape and fertilized soil. VF, on the other hand, is notorious for using a large amount of electricity, triggering the alarm of the essential of finding alternative source of energy. Renewable resources are currently drawing attention to sub the conventional electrical power. Hence, solar power became a popular choice for supplying energy to such devices since it is both practical and readily available. Solar lighting systems have a lot of promise, as demonstrated by a UK research that examined the potential cost reductions associated with their use. The analysis reveals 56% to 89% of possible savings [2]. The use of solar energy in vertical farming would thus benefit the entire process and make it even more dependable and sustainable.

Incorporating solar energy into vertical farming systems is a sustainable approach that enhances the overall efficiency and environmental impact of the agricultural process. Research indicates that integrating solar panels into vertical farming structures can provide a reliable and renewable energy source, powering LED lights, climate control systems, and other essential equipment. Such incorporation not only reduces the dependence on conventional energy grids but also mitigates the contribution of carbon by-product associated with the production of food. However, power intermittency and energy storage of solar panels are still of ongoing challenges, in particular integration into vertical farming. Hence, more studies are in need to optimize a sustainable and self-sufficient agricultural model.

Furthermore, studies emphasized that the incorporation of solar energy in vertical farming can lead to increased energy autonomy and cost-effectiveness over the long term. Solar panels strategically positioned on the vertical farming structures, harness sunlight for electricity and minimizing reliance on conventional power sources. This sustainable energy approach associates with the continuous demand for eco-friendly agricultural practices, addressing concerns related to climate change and conventional energy consumption in food production.

Innovations in solar technology, such as advancements in photovoltaic efficiency and energy storage solutions, are crucial in overcoming challenges associated with intermittent sunlight availability. Ongoing research explores the optimization of energy capture and storage mechanisms to ensure continuous and reliable power supply, regardless of weather conditions or time of day.

Moreover, incorporating solar energy in vertical farming is vital to the development of off-grid farming solutions, particularly in remote areas. This approach not only facilitates increased food production in regions with limited access to conventional power but also promotes sustainable agriculture practices that prioritize environmental stewardship.

As the field continues to evolve, interdisciplinary collaboration between agriculture, engineering, and renewable energy sectors becomes pivotal. This collaborative effort aims to refine and scale up solar-powered vertical farming systems, fostering a more feasible and sustainable future for agriculture.

Although one of the most flaws in VF systems is the high energy consumption, incorporation of renewable energy sources (RE) such as solar and wind could mitigate the capital and operation costs. Hence, utilizing renewable energy in VF systems have intensively addressed by recent literatures to assess the promotion of sustainability in urban agriculture.

System design

The prototype was initially built based on the standards of greenhouses, but it was customized to meet certain specifications. The final dimensions and design of the building are illustrated in Fig (1). Carbon steel, a material with high tensile strength and rigidity, was selected as the main structural material for the prototype. Insulation was selected to minimize the energy interaction between the system and the surroundings. Factors such as thermal resistance, ageing, moisture accumulation and thickness are prioritized during the selection process.

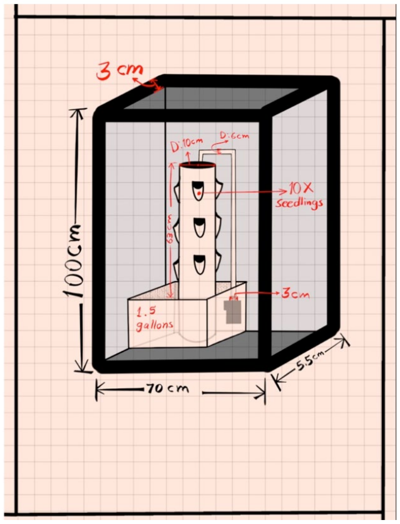

Fig. (1) Dimensions of the Tower Farm

LED lighting is the best choice for indoor farming for various reasons. It can reduce energy consumption for different crops as well as easy to control. The quality can be tailored to suit the photosynthetic pigments and photoreceptors of the crop by adjusting its intensity and spectrum[2]. This is important in vertical farming since plants can sense and respond to changes in light intensity and illuminance. LED lights can also influence the flavor, nutritional value and shelf life of crops.

Red/blue LED lights can enhance the growth and biomass of C. LED lights can also improve the growth, color, flavor, and phytonutrient content of leafy greens in controlled environments by adjusting the light spectrum [2].

Furthermore, LED lights are more energy-efficient than other forms of lighting, as they consume less energy for running lights and climate management [3]. LED lights also affect the heat load of the room. The heat load was lower when LED lights were off, and higher when they were on [4].

A recent experiment showed that LED grow lights accounted for 78% of the daily heat load on average, and also accelerated the processes of respiration and evaporation in plants. Moreover, an energy balance analysis revealed that LED lighting increased the evapotranspiration and heat loads by up to five times compared to a scenario without LED lighting. Therefore, it is important to choose the right type and intensity of LED grow lights for different plants and growth stages [4].

Solar resource assessment

Saudi Arabia, has an excellent solar power potential due to its long hours of light, few days with clouds (particularly, in eastern province) , and elevated Direct Normal radiation DNI, which reaches a peak power density of 4800 kWh/m^2/year [5].

Such places are viable and highly positioned among the forefront of countries with the ability to produce electrical power using solar energy [6].

The DNI is a crucial factor to consider when evaluating the viability of a geographical area for the implementation of CSP technology. It is worth mentioning that CSP systems are generally considered viable in locations where the direct normal irradiance (DNI) surpasses 1800 kWh/m^2/year [7, 8].

FPS modeling:

This section examines the viability of the suggested FSP systems according to the conditions of east province in Saudi Arabia. Annual energy output (GWh), which refers to the sum of the hourly energy produced over the course of a year. The following equation is used to calculate annual energy output:

$$AE = \sum_{t=1}^{t=8760} Q_t$$

where *t* represents time (hour) and Q_t stand for the generated energy. The capacity factor, defined as a ratio of the total number of hours of electricity generated in an FSP plant relative to its nominal capacity over the course of one year, can be computed by the following equation:

$$Capacity\ Factor = Net\ Annual \frac{Energy \frac{\frac{kWh_{ac}}{yr}}{System\ Capacity\ (kWh_{ac})}}{8760}$$

$$CF = \frac{\frac{AE}{system\ capacity}}{8760\ (hr/year)}$$

The annual energy and capacity factor in eastern province in Saudi Arabia are determined to be 209 GWhr and 72.5% respectively.

Two 300-watt solar panels were utilized to provide the power demanded by the VF system. The size of each panel is 164 x 99.2 x 4 cms**.** The output electrical energy (E), in kWh, is determined from the following expression:

$$E = A \times \eta \times I \times PR$$

where: A= area of the solar panel;
η= solar panel efficiency (roughly 15%);
I = average annual solar radiation on titled panels (5.337 kWh/m^2 day for the optimal tilt angle 20.833°)
PR= performance ratio (average value = 0.75)

Results and discussion

A series of tests have been conducted on the system, including lighting, cooling, humidifier, dehumidifier and irrigation system, as illustrated in Fig. (2). The system run twice for each test: full day and half day. To create a suitable environment for lettuce growth, Styrofoam insulation was utilized to line a wooden frame that holds the nutrient solution as well as serves as a floating platform for the plants. Since the optimal conditions for lettuce are 75-85% humidity and 18-24 °C temperature, growth lights, an evaporative cooler, a humidifier, and a dehumidifier were installed to control the system thermal conditions. The growth lights have a power of 16W, while the evaporative cooler consumes 65W. A submersible pump utilized to circulate the nutrient solution requires 13W to operate at maximum flow rate of 700L/h and vertical head (H_{max}) of 1.0m. The humidifier has a wattage of 25W, and it can filter impurities from water and adjust the fog intensity. The dehumidifier, on the other hand, operates at consumption up to 25W and it can recover about 0.4kWh to dry.

The nutrient solution was pumped from the reservoir to the top of the garden tower, where it drips down over the exposed roots of the plants. A timer ensures that this process is repeated regularly to provide adequate oxygen, water, and nutrients to the plants.

The energy produced by each panel with specification elaborated earlier is 0.977 kWhr for a total of 1.95 kW hr. Equipment of the system needs 1.728 kWhr to operate at full load condition for 12 hrs. Hence, the system is durable and the technologies performed well from both the intended purpose and the eco-friendly environment.

Fig. (2) Lighting and humidification processes

Conclusion

This paper presents a design of a solar powered vertical farm that uses aeroponic tower garden technology to grow lettuce in a closed chamber. The main objectives of this design are to address the scarcity of power source in remote area, the reduction of environmental impact resulted by conventional agriculture, and the provision of fresh and healthy food for local consumption by incorporating of renewable energy. The paper describes the design process, the prototype fabrication, and the testing and analysis of the system. The design process involved selecting the appropriate materials and components for the aeroponic tower garden, the solar system, and the control system. The aeroponic tower garden consists of a vertical structure with multiple planting ports that spray nutrient-rich water to the roots of the plants. Design of the solar system consists of photovoltaic panels, batteries, charge controller, and inverter that provide electricity to power the pumps, AC, humidifier, dehumidifier, sensors, and lights.

The prototype was tested twice and produced the required environment for producing healthy and fresh lettuce. The paper discusses the results and analyses of the prototype performance, comparing it with other similar systems and highlighting its advantages and limitations.

References

[1] Yahya, O., Yahya, G., Al-Omair, A., Yahya, E., Jassim, E., Djavanroodi, F. (2023). "Aeroponic tower garden solar powered vertical farm". Volume 31, Pages 287 - 2982023 International Conference on Advanced Topics in Mechanics of Materials, Structures and

Construction, AToMech1 2023Al Khobar 12 March 2023. https://doi.org/10.21741/9781644902592-30

[2] Jahan, N., Moody, B., Kerr, J., Cynthia, D, & Lawson, C. "Grow lights for your vertical garden: A complete guide. Garden Tabs. Retrieved", February 16, 2022.

[3] 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

[4] Omar Yahya, Gharam Yahya, Ahmad Al-Omair, Emad Yahya, Esam Jassim, Faramarz Djavanroodi, Aeroponic tower garden solar powered vertical farm, Materials Research Proceedings, Vol. 31, pp 287-298, 2023. https://doi.org/10.21741/9781644902592-30

[5] Esam Jassim, "Improvement of Indoor Air Distribution by Utilizing Small Fans Powered by Solar Energy", International Journal of Computational Physics Series 1(2), 1-8, 2017. https://doi.org/10.29167/A1I2P1-8

[6] Kazem, Hussein A., et al. "A review of dust accumulation and cleaning methods for solar photovoltaic systems." *Journal of Cleaner Production* 276 (2020): 123187. https://doi.org/10.1016/j.jclepro.2020.123187

[7] Erica Zell, Sami Gasim, Stephen Wilcox, Suzan Katamoura, Thomas Stoffel, Husain Shibli, Jill Engel-Cox, Madi Al Subie, "Assessment of solar radiation resources in Saudi Arabia", Solar Energy, Volume 119, 2015, Pages 422-438. https://doi.org/10.1016/j.solener.2015.06.031

[8] M. Enjavi-Arsanjani, K. Hirbodi, M. Yaghoubi, "Solar Energy Potential and Performance Assessment of CSP Plants in Different Areas of Iran", Energy Procedia, Volume 69, 2015, Pages 2039-2048. https://doi.org/10.1016/j.egypro.2015.03.216