Greenhouse and Its Integration with Photovoltaic System: An Application Perspective

Manuj Bhardwaj*, [1] and Shikha Singh*

www.RERICProceedings.ait.ac.th

Abstract *–Due to exponential rise in population in recent years, consumption of agricultural products is increased in the same trend. Therefore, it becomes a challenge to cater the need of individual in limited land. Further, crops have different cultivation requirements such as water level, temperature, humidity, wind speed, geographical location etc. which is affected by the climatic changes due to increase in greenhouse gas emission. The current global energy trends and climate challenges further drives force to move away from carbon-intensive fossil fuels. To mitigate the effect of climate variations, Greenhouse has proven as promisable solution for food security, enhanced crop production and promotes sustainability in controlled environment in global agricultural sector. Alternate energy source (Solar energy) is used to facilitate greenhouse in rural areas where electric grid is not available. An exhaustive study has been done in this paper to give a fresh application based approach for cultivation of various crops and vegetables using greenhouse.*

Keywords – Agriculture, fossil fuels, Greenhouse, photovoltaic, renewable energy.

1. INTRODUCTION

Rapid increase in population and increased consumption of fossil fuels worsen the global crisis of "food security" as one of the most vital aspects of Global SDGs. Food sector is adversely affecting due to limited arable land and drastic variations in the weather conditions. Food and Agriculture Organizations of the United Nations and scientists around the globe are having great concern for efficient food production to fulfill the demand of exponentially increasing population [1]. In recent years, researchers focused on alternate energy sources (solar) to fulfill increased food demand in limited land. Compared to conventional farming practices, greenhouse agriculture offers a possible substitute to fulfill the world's expanding food demand. It is mainly used to protect crop from cold/hot climatic conditions. Greenhouse is a translucent structure and solar radiation falls with inclined angle on greenhouse that creates a suitable microclimate inside it to control humidity, indoor temperature, solar irradiance, CO_2 concentration etc. to protect crops from external environment to increase its production and quality. Air temperature inside greenhouse is dependent on various factors such as outside climatic conditions (ambient temperature and solar radiation), greenhouse design parameters as cladding material characteristics, orientation, shape and rate of air change etc. which affect the thermal behavior and heating/cooling [1].

Temperature inside greenhouse is maintained using solar radiation or by heating using artificial sources, such as circulating hot water, steam or hot air [1]. Ventilation is necessary to avoid overheating in the greenhouse. Passive ventilation methods are roof opening and window opening whereas active ventilation methods are air circulation using electric fan are commonly used in greenhouses. Direct/Indirect Sun energy can be used with the help of photovoltaic (PV), solar collector, heat exchangers etc. The Sun energy is trapped and converted into electrical energy and/or thermal energy using PV is used to heat water and air, crop drying, solar tractor, solar pump etc [1-2]. Solar is the most user-friendly, clean, renewable power source to meet human energy needs [3-5]. According to the International Energy Agency (IEA), photovoltaic has demonstrated its worth in the energy industry by contributing 6000 TWh of Photovoltaic electricity until 2050, approximately 16% of the world & total electricity consumption [2]. Large land areas are required to absorb solar energy into the atmosphere. Use of PV panels is an attractive renewable energy technology as they avoid emission of greenhouse gases, use abundant and reliable power resource and provide a long life of around 20-30 years. The complete thermal conduction using photovoltaic system can be used for heating of inner temperature of greenhouse. The performance of solar cells is also improved by this thermal energy extraction from PV [2].

An opaque PV thermal module on top of the roof integrated with greenhouse is used to facilitate necessary electrical energy for the operation of appliances, ensuring a clean atmosphere and climate. These constructions are favorable for hot climatic environment as the shading effect maintains the balance between crop yield and electricity production. The concept is founded on photo-voltaic thermal (PVT) principles, which provide the thermal and electrical energy needed to maintain a controlled environment (CE) greenhouse even in remote regions of developing and impoverished nations. The greenhouse integrated semi-transparent photo-voltaic thermal (GiSPVT) give thermal, electrical and solar irradiations for photosynthesis process as well as

*Shri Ramswaroop Memorial University, Lucknow Deva Road, Barabanki-225003, India.

[1] Corresponding author;
E-mail: manjubhardwaj.271981@gmail.com

provides protection during extreme climatic conditions [3-4].

Rigorous review of greenhouse, greenhouse along with PV and other applications of solar energy have been carried out in this paper. This paper categorized in five sections. Starting with section 1 as introduction, the other sections covers the literature survey of greenhouse and its integration with PVT, classification and future development followed by future trends and recommendations.

2. REVIEW OF LITERATURE OF GISPVT

The output yield of agriculture products using greenhouse minimizes the post-harvest losses by adopting latest technologies for cultivation, protecting crop from harsh weather conditions etc. Moreover, growth and quality of plants and animals are affected with outside temperature of environment (Optimum temperature for the growth of plants and animals are in the range of 12°C to 30°C) [5]. To protect plants and animals from the harsh climatic conditions, CE greenhouse may be used which improve crop cultivation. As greenhouse is generally constructed in rural areas where electrical supply/grid connectivity is not available. Therefore, to make system self sustainable, greenhouse may be integrated with PV. This configuration not only enhances reliability but also provide desired temperature. Therefore, to enhance the performance of greenhouse, PV system is integrated to increase efficiency of system and to make the self sustainable system as shown in Fig. 1.

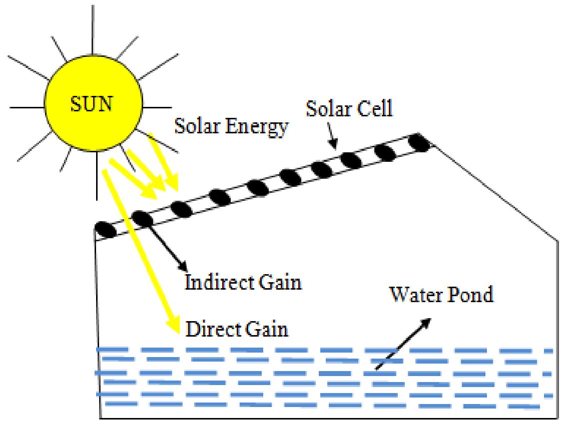

Fig 1. Greenhouse integrated with photovoltaic system (PVT).

The un-even GiSPVT for aquaculture is depicted in Fig 1. Depending on the solar radiation available, the direct gain is obtained through the non-packing area of semi-transparent solar power module, glazed wall, and the north roof of the pond's water surface [6]. Additionally, water from the bottom of solar cells indirectly gains thermal energy through room air of greenhouse.

The water temperature inside greenhouse is directly dependent on depth of water and saturation in water temperature can be achieved after 0.5 m of water's depth because of its high heat capacity. The temperature of water can be further increased by decreasing packing factor of PV mounted onto the roof. Also, after experimental analysis, it's concluded as electrical efficiency of PV system decreases by increasing the temperature of solar cell used in PV system [7]. The selection and installation of GiSPVT is based on the types of crops and climatic conditions of that area.

In recent years, various scientists are working on issues related with greenhouse heating system using active and passive methods. An uneven span structure of greenhouse integrated with a semitransparent photovoltaic thermal (PVT) system was considered [7]. Within the greenhouse, a pond is taken into consideration. This feature has the potential to be utilized for algaculture, aquaculture, and thermal storage. The researchers concluded as average temperature of various solar cells increases with a decrease in electrical efficiency of the PV module and also the night time temperature in the greenhouse is 5˚C higher than the outside temperature [7]. The performance of system was enhanced by self sustainable system using earth air heat exchanger and semi-transparent photovoltaic thermal (SPVT) greenhouse system is constructed for hot climatic weather condition for the plant production. The temperature inside greenhouse was recorded as 9°C less than ambient temperature and also generated electrical energy of 124 kW [8]. This electrical energy was useful in driving the appliance such as light, fan, motor etc [8].

The agriculture sector may greatly benefit from Sun energy, especially in the field of food preservation through drying using solar. It makes it possible to cut the amount of electricity produced altogether from fossil fuels by 27% to 80%, which lowers the price of drying the crops [9]. Drying is the method of removing water or moisture to a safe or acceptable level from a variety of things, including food and agricultural products, without affecting the crop's quality. Making the drying system self-sustaining is the primary goal achieved by using greenhouse integrated PVT air collector. These drying systems are typically needed in remote locations where grid is not available. Compared to traditional drying systems, the greenhouse integrated PVT air collector drying offers stringent temperature concluded by researcher [10]. Solar drying proposed system offers cheap crop drying in comparison to electrical drying system as drying is based on renewable energy.

Heating of outdoor swimming pool was achieved by using electrical power generated by using fossil fuels which requires electricity. These type of systems are not self sustainable. The temperature of water in an outdoor swimming pool was increased using compound parabolic collector-flat plate collector (CPC-FPC) collector and evacuated tube collector [11]. In cold climates, the evacuated tube and CPC-FPC collector's maximum thermal gain to pool water; but, in order to run the system, they require grid electricity [11]. Therefore, the photovoltaic thermal compound parabolic collector (PVT-CPC) solar collectors were used to heat the outdoor swimming pool temperature as depicted in Fig 2.

The PVT-CPC collector saves a significant quantity of fossil fuels, lower human-caused CO_2 emissions into the atmosphere, and satisfies swimming pools requirement of heat and electricity.

To make system self sustainable, the PVT-CPC collector is best suited for thermal heating applications, since it can produce both thermal and electrical energy. This technology provides carbon free environment. Based on numerical calculations and analysis, it was summarized that the PVT-CPC collectors provides sufficient heat and electricity [12].

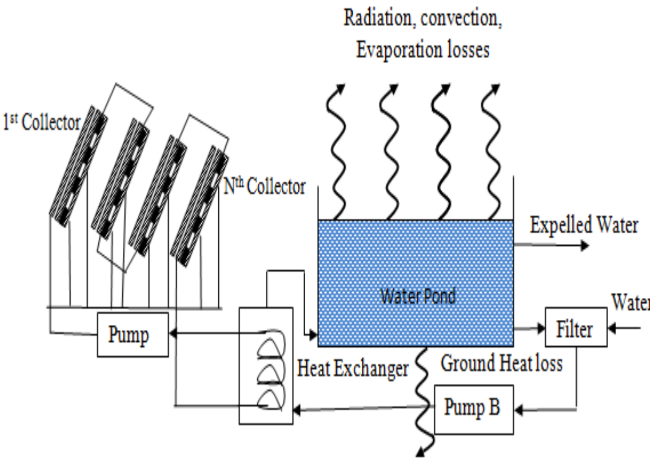

Fig 2. Outdoor swimming pool with solar water collector.

Further, GiSPVT system as shown in Fig. 3 is designed to grow crops in desert (unfertilized) land. As per experimental results available at a remote location, most of the vegetable and crops provide optimal yield with less packing factor since GiSPVT requires a high light intensity. Earth and burning of dung cake maintains the temperature within GiSPVT and reduces the heat losses from GiSPVT to ambient air [13].

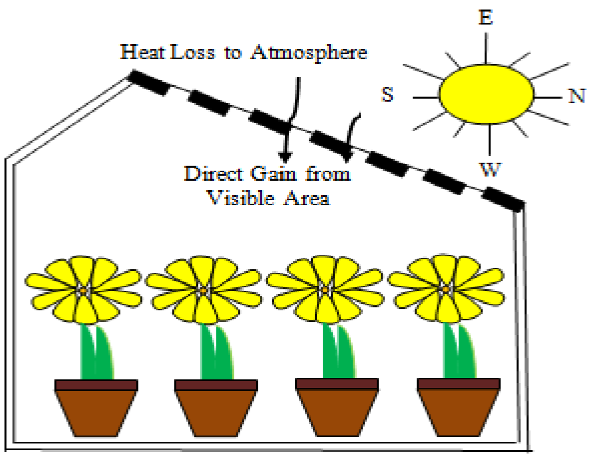

Fig 3. Green house integrated with semitransparent PVT system.

In [14], a semi-transparent PV system based on micro spherical solar cell was fabricated for greenhouse shading management. The electrical energy can be effectively managed in greenhouses to improve crop quality and production while reducing the need for fuel and grid electricity, especially in areas with high levels of solar radiation [14].

3. CLASSIFICATION OF PHOTOVOLTAIC SYSTEM

Exponential rise in the demand of energy calls for notable growth in area of solar cells and different photovoltaic arrays in recent years. There are hundreds of manufacturers of PV cells in the world, and there are several technologies existing in the market. There are commercially three main types of PV cells available in the market named as mono-crystalline silicon PV solar cell, Poly-crystalline silicon PV solar cell and thin- film amorphous silicon PV.

Currently, 93% of global market is dominated by first two categories, while the approximately 4.2% is used in thin film. Other types of solar cells are hybrid solar cells, concentrated PV solar cell, multi junction solar cells etc are having limited applications.

The technologies based on silicon are amorphous (a)-Silicon, multi-crystalline (mc)-Silicon, crystalline(c)-Silicon are the leading technologies having efficiencies at cell level is 12%, 24%, and 19% [15]. Two types of non-flexible PV modules are made using c-Two types of non-flexible PV modules are made using c-Silicon solar cells namely (i) Tedlar based opaque PV modules and (ii) Glass based transparent PV modules. Semi-transparent PV modules are made using glass base transparent PV module [15].

A thin layer or thin film of photovoltaic material is deposited on a substrate to create a thin-film solar cell (TFSC), also known as a thin-film photovoltaic cell. The thickness of this layer is broad and varies in the range of few nanometers to tens of micrometers as different photovoltaic materials are deposited using deposition techniques on a different variety of substrates [16]. Thin-film photovoltaic cells are classified based on the utilization of photovoltaic material.

Four categories as Dye-sensitized solar cell (DSC), Cadmium-Telluride (CdTe), Organic solar cell, Coppe-indium-gallium-selenide (CIS or CIGS), and Amorphous Silicon (a-Si) [13-15] in the third generation of solar cell has been reported. Thin film cells have an efficiency of about 6–12%, making them appropriate to be used in Building Integrated PV (BIPV) systems and highly suitable for the applications of windows and facades.

The efficiency of solar cells is enhanced by using micromorph triple junction Ge/GaAs/GaInAsP materials [17], but these technologies are very difficult and costly as fabrication of triple junction solar cell is a tedious process. Hence, these solar cells are mainly used for satellite applications. In order to minimize the utilization of more expensive cells, these cells are employed in high concentration mode for terrestrial applications.

Using optical reflectors, concentrated light from 200 to 500 times on area of 1 cm^2. Day-to-day tracking of solar energy in two dimensions maintains the sun's location on the gadget area so that maximum solar radiation can be received to obtain maximum efficiency [18-20].

4. OBSERVATION AND APPLICATION OF GREENHOUSE

Various literature review on greenhouse integrated with solar-photovoltaic panels which is based on design and application were consolidated in Table I. The major aim of this is to give a clear impact that which type of structure is suitable for a particular application and on climate parameters.

Various structures has been rigorously reviewed and summarized for a better understanding [6-21].

Table 1. Greenhouse integrated with solar-photovoltaic panels based on design and its applications.

S.No	Structure	Solar cell material used/PVT	Applications /Weather conditions	Observations	Reference
1.	Quonset type Greenhouse	Multi-crystalline silicon based solar cell (c-Si)	Vegetables/ cold climatic conditions	• Decrease in water temperature by increasing depth of water. • Water temperature further increased by lowering packing factor of PVT. • Electrical efficiency of PVT decreases with the increase in temperature of PVT is observed.	[6]
2.	Greenhouse made with glass and green jute	Semi-transparent photovoltaic thermal (SPVT)	Plants/hot climatic condition	• Plant temperature decrease with increase in air temperature. • The temperature of air for growth of plant reduce by 9 °C to 10.5 °C.	[7]
3.	Greenhouse made with glass.	Semi-transparent photovoltaic thermal (SPVT) system	Aquaculture and algaculture/ winter climatic condition	• Solar cell temperature increases and reaches to peak value and then gradually decreases in sunshine hours. • Temperature inside greenhouse is 5°C more than ambient air temperature.	[8]
4.	Greenhouse A-Slope made with glass	Glazed PVT solar collectors and drying system	Crops drying/ winter climatic condition	• Temperature controllability is superior then other drying systems. • By altering the air mass flow rate and PV module packing factor, a single drying system may be used for various applications.	[9]
5.	No Greenhouse	PVT-CPC collector and PVT-FPC	Outdoor swimming pool /cold climatic condition	• Provide sufficient heat and electrical load demand of the swimming pool. • Reduces CO2 emission. • Save fossil fuel.	[10]
6.	No Greenhouse	PVT Thermo-electric coolers (TEC) collectors	Outdoor swimming pool/ cold climatic condition	• Series connected collectors provide better exergy then parallel connected.	[11]
7.	No Greenhouse	PVT compound parabolic concentrator (CPC) collector is placed over the semi transparent photo-voltaic flat collector	Outdoor swimming pool/ cold climatic condition	• System generates electricity to run pump for water circulation. • System generates electricity to heat water. • Self sustainable system.	[12]
8.	Ridge and furrow type green house	Uneven PVT	Off season crop/ cold climatic condition	Following conditions provide maximum crop yielding: • Packing factor area is 25% of total area of semi- transparent PV module. • The ratio of sand, soil and organic fertilizer as 40%, 40%, and 20% respectively. • Burning dung cake maintains CO_2 level. • Heat loss minimization.	[13]
9.	Glass based greenhouse	Spherical micro-PV cells	Crop/cold climatic condition	• Improve agricultural production. • Quality improvement. • Reducing fuel consumption. • Reduce grid electricity usage.	[14]
10.	Plastic based greenhouse	Solar based hot air aerator	Fish/winter climatic condition	• Faster fish growth.	[15]

5. FUTURE TRENDS AND RECOMMENDATIONS

Future greenhouses are expected to prioritize energy through advanced insulation, smart climate control systems, heat exchanger integration for stringent temperature control, mitigation of CO_2 level. Vertical farming is another emerging technology involves growing of crops in stacked layers using artificial lighting method and controlled environment ensuring maximized land use and increased crop production per unit area. Future greenhouses are expected to prioritize energy through advanced insulation, smart climate control systems, heat exchanger integration for stringent temperature control, mitigation of CO2 level. Vertical farming is another emerging technology involves growing of crops in stacked layers using artificial lighting method and controlled environment ensuring maximized land use and increased crop production per unit area.

REFERENCES

[1] Karambasti B.M., Naghashzadegan M., Ghodrat M., Ghorbani G., Simorangkir R.B., Bakhsh A.L.,2022. Optimal Solar Greenhouses Design Using Multiobjective Genetic Algorithm. *IEEE Access* 10: 73728-73742.doi: 10.1109/ACCESS.2022.3189348

[2] Pieters J. G., Deltour J. M.,1999. Modelling Solar Energy Input in Greenhouses. *Solar Energy*, Vol 67:1-3.

[3] Prakash A., Kumar M., Manchanda H., Grewal R., 2021. A Review on Solar Flat Plate Air Collector With Different Design Modifications. *International Multidisciplinary Conference*, 65-78, ISBN: 978-93-91535-12-14.

[4] Siddharth S., Mohd K.K., Manabendra P, 2015. Performance Enhancement of Solar Collector- A Review. *Journal of Renewable and Sustainable Energy reviews*, 49: 192-210.

[5] Singh S., Tiwari, G.N., 2021. Thermal Analysis of Uneven Span Greenhouse Integrated Semitransparent Photovoltaic Thermal System (GiSPVT). *International Journal of Engineering Research & Technology*,10: 240-249..

[6] Tiwari G.N., Singh S., Singh Y.K., Singh R.K., 2022. An Overall Exergy Analysis of Un-even Greenhouse Integrated Semi-Transparent Photovoltaic (un-even GiSPVT) System: A Thermal Modelling Approach. *International Journal of Ambient Energy*, 43: 6772–6781.

[7] Yadav S. , Panda S.K., Tiwari G.N., Ibrahim M., Abdullah A.H., Alsadon A., Mohammed R., A. Tiwari, 2022. Semi-Transparent Photovoltaic Thermal Greenhouse System Combined With Earth Air Heat Exchanger for Hot Climatic Condition. *Journal of Thermal Science and Engineering Applications* , 14: 71-79.

[8] A. Mellalou, A. Mouaky, A. Bacaoui, A. Outzourhit, "A Comparative Study of Greenhouse Shapes and Orientations Under the Climatic Conditions of Marrakech ,Morocco", International Journal of Environmental Science and Technology, August 2021.

[9] S. Tiwari, S. Agrawal, G.N. Tiwari, "PVT Air Collector Integrated Greenhouse Dryers", Renewable and Sustainable Energy Reviews, 2018, PP 142-149.

[10] A. K. Singh, G.N. Tiwari, R.G. Singh R.K. Singh, "Active Heating of Outdoor Swimming Pool Water Using Different Solar Collector Systems", Journal of Solar Energy Engineering, August 2020, Vol 142, PP 0410081-0410089.

[11] G.N. Tiwari, R.K. Singh, S.K. Sinha, A.K. Singh, "Study of Performance of the Flexible (Al-Based) N-PVT-TEC Collectors in Different Configurations", Journal of Solar Energy Engineering, December 2023, Vol 145, PP 610031-6100311.

[12] A.K. Singh, G.N. Tiwari, "Performance of Active Solar Heating of Outdoor Swimming Pool: A Constant Collection Temperature Mode", Asian Journal of Physics,2021, Vol 30, No 1, PP 185-194.

[13] G.N. Tiwari ,A.Tiwari,"Optimization of Packing Factor For Maximum Electric Power And Crop Yield in Greenhouse Integrated Semi-Transparent Photo-voltaic thermal (GiSPVT) System in Desert Land: An Experimental Study", e-Prime - Advances in Electrical Engineering, Electronics and Energy, 2021, PP 1-15.

[14] Z. Li, A. Yano, M. Cossu, H. Yoshioka, I. Kita, Y. Ibaraki, "Electrical Energy Producing Greenhouse Shading System With a Semi-Transparent Photovoltaic Blind Based on Micro-Spherical Solar Cells", Energies 2018, PP 1-23.

[15] P. Yongphet, R. Ramaraj, N. Dussadee, "Effect of Greenhouse Cages Integrated With Using Solar Energy on The Growth Performance on Freshwater Fish", International Journal of New Technology and Research, March 2016, Vol 2, PP 100-107.

[16] K.D.T. Ngo, S.K. Mishra, S. Thekkevalappil, "Pulse Width Modulator With Carriers Derived From Converter Waveforms," IEE Electronics Letters, Feb 2005.

[17] K.D.T. Ngo, S.K. Mishra, M. Walters, "Synthetic Ripple Modulator For Synchronous Buck Converter," IEEE Power Electronics Letters, December 2005.

[18] S.K. Mishra, S. Zhou, G. Schuellein, "Design of Average Current Mode Control With Limited DC Gain Based Redundant Parallel Multiphase VRM," Proceedings of PCIM Europe, Nuremberg, May 2006.

[19] D. Papadopoulos, M. Alvanou, A. Lattos, K. Ouroulis and I. Giantsis, "Tropical Shrimp Biofloc Aquaculture within Greenhouses in the Mediterranean: Preconditions, Perspectives, and a

Prototype Description" Journal of fishes, MDPI, 2024, Vol 9.

[20] J. Gao, S. Li, F. Wu, L. Jiang, Y. Zhao, X. Zhang, "Study on efficient heating method by solar coupled air source heat pump system with phase change heat storage in severe cold region", Journal of Applied Energy, 2024, Vol 367.Doi:https://doi.org/10.1016/j.apenergy.2024.123206.

[21] Kyu-In Lee, Yoon-Boum Cho, Hwang Yi, "Improving The Environmental Performance Of Fish-Farming Houses A Comparative Passive Design Study In South Korea", Journal of Green Building, 2024,