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Comparative Analysis of Microclimatic Conditions and Energy Efficiency in Normal and Agrivoltaic Greenhouses for Flower Cultivation

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Abstract: - Greenhouse cultivation plays a critical role in modern agriculture and is especially important for the floriculture industry, where controlled environments are required to achieve high-quality flowers. Though effective at creating ideal growing conditions, traditional glass greenhouses are highly energy-dependent and thus come with high operational fees and more significant environmental sustainability problems. Novel agrivoltaic greenhouses simultaneously produce crops and electricity, merging photovoltaics (PV) with traditional greenhouse structures. The main interest of this study is the detailed and more in-depth comparison between a regular greenhouse and an agrivoltaic greenhouse, considering energy efficiency, economic analysis, and environmental impact.

The present study focuses on evaluating microclimatic parameters in greenhouses according to different climate conditions, designing a controlled system for the optimum growth of flowers using solar Energy, developing an agro-voltaic and speculating if it's sufficient for fulfilment. The study aims to establish the feasibility of this new proposed agro-voltaic Greenhouse in different bioclimatic conditions prevailing across India.

It assesses annual output, carbon footprint reduction potential and maintenance expenses, and crop yield impacts with microclimate improvement measures. It is hoped the research will usefully examine these issues by focusing on harvesting advantages for crop yields and identifying opportunities in energy costs and potential environmental offsets that could be provided through agrivoltaic greenhouses. These results are anticipated to validate the status of agrivoltaic greenhouses as a key player in promoting sustainable horticulture, bringing them into line with global sustainability priorities and providing implementable solutions for addressing complications encountered by agricultural scenarios.The main objective of the present work is to explore some essential parameters affecting microclimate in greenhouses for flower production based on different temperature indicators. The aim is to establish a technique for storing the greenhouse microclimate in flowering boost. This study also intends to develop an agro-voltaic system coupled with the greenhouse energy load. This agro-voltaic greenhouse system, as being designed, will be validated in all climatic zones of India.

Keywords: Energy requirements, Greenhouse, Microclimates, Photovoltaic systems, Energy efficiency, sustainable agriculture, Solar.

1. Introduction

Greenhouse cultivation is necessary in contemporary agriculture as it helps flourish with flowers. The old-school greenhouses provide the best growth conditions by maintaining the perfect Temperature, humidity, and CO2 concentrations. But often, these systems are energy-hungry, needing lots of external power to keep the microclimate under check. Such high energy consumption leads to unnecessary operational costs and equally important environmental sustainability needs due to the enormous carbon footprint established here. State His reasoning: The immediate need for more sustainable agricultural practices has prompted the search to experiment with alternative greenhouse technologies.

Overview of Greenhouse Cultivation in Modern Agriculture

The modern agricultural revolution has integrated agriculture with its cornerstones, such as greenhouse cultivation. Greenhouse cultivation allows the agriculturalist to grow all types of plantations in all conditions; it

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doesn't rely on the weather conditions of a specific region. A greenhouse is a climate-controlled location where the growth factors such as Temperature, light, humidity, and others can be monitored, and the requirements of the plants can be adjusted to grow ideally in conditions of the climate where it should be reduced. The greenhouse cultivation method is mainly suited for climatically adverse conditions and less available agricultural land. Importance of the environment for floriculture Flowers, one of the main things being sold by humans, are cultivated from floriculture and require habitats taken care of every hour. Floriculture is the discipline of cultivating flowers and ornamental plants. Flowers are sensitive to climate change; they need a specific temperature, humidity, and even CO2 concentration for different types of flowers for proper high-quality flower production. Greenhouse climatic conditions help control the growth of crops as well as protect them against pests and diseases.

Challenges with Traditional Greenhouse Systems

Although it has its benefits, there are numerous drawbacks to typical greenhouse systems.

1. Excessive Energy Use: Greenhouses need powerful heating, cooling and lighting systems to keep their plant growing in the best conditions. Most of these systems are energy-intensive because they rely on outside sources for power. In colder climates, heating represents 60-80% of a greenhouse's energy consumption. In warmer regions, like Dubai, we would also expend Energy in heating our water to prevent freezing similarly and in stocking coolants to avoid overheating, putting more pressure on cooling systems.

2. High Operational Costs: The increased consumption of Energy leads to high operational costs for the plant. In addition, farmers are obligated to incur significant expenses to maintain the necessary microclimatic conditions, which can be costly - especially for small and medium-scale suppliers. Energy, heating/cooling m

Agrivoltaic Greenhouses: A Sustainable Alternative

Agrivoltaic greenhouses are innovative interspace solutions integrating photovoltaic (PV) systems and classical greenhouse buildings. This unusual design offers the on-site capacity for a year-round crop and solar Energy generation, providing a means of meeting dual needs concerning agricultural and Environmental production. Solar panels can reduce dependence on foreign Energy and keep down the Greenhouse's carbon footprint, making it an environmentally friendly option. In addition to providing the Energy needed for the Greenhouse, this integration also supports larger environmental sustainability goals.

Microclimate control in greenhouse environments has also been found to be important by Ali, et al., 2016 and Singh et al. Additionally, research by Aroca-Delgado et al. (2019) and Suzuki & Takahashi (21019) showed the possibility of integrating PV systems in greenhouses to improve energy efficiency. Such advances will require comparative studies to assess the efficiency and scalability of agrivoltaic implementations.

Objectives and Expected Outcomes

This paper compares traditional and agrivoltaic greenhouses, focusing on key parameters directly affecting flower cultivation. These parameters include annual energy generation, carbon footprint, maintenance costs, crop yield, and the effectiveness of microclimate optimization techniques. By evaluating these factors, the study seeks to determine the potential advantages of agrivoltaic greenhouses regarding energy efficiency, cost-effectiveness, and environmental impact. Additionally, the paper examines how the integration of solar panels influences the overall productivity and sustainability of flower cultivation within greenhouse environments.

The comparison between traditional and agrivoltaic greenhouses is crucial for understanding the viability of adopting agrivoltaic systems on a larger scale. The findings of this study are expected to highlight the potential of agrivoltaic greenhouses to maintain and potentially enhance crop yields while offering significant energy savings and environmental benefits. Through a detailed analysis of energy consumption, cost implications, and microclimate control, this paper demonstrates that agrivoltaic greenhouses can advance sustainable horticultural practices. This innovative approach aligns with the growing global emphasis on sustainability and offers a practical solution to some of the most pressing challenges the agricultural sector faces today.

2. Literature Review

The importance of microclimate control in greenhouses has been recognized for decades, with many studies underlining the critical effects that Temperature, humidity, and photosynthetic photon flux density (PPFD) exert on plants. Ali et al. From what has been discussed in (2016), a fuzzy logic controller was used for Temperature and humidity control of the agricultural greenhouses, showing that an advanced controlling system can keep tipping conditions correctly. In the same way, Singh et al. (2016) also conducted a detailed review of modelling greenhouse microclimate under cropped conditions. They stressed the importance of an accurate control environment for maximizing crop yield and quality.

Technology in greenhouses and controlled environment agriculture has improved significantly; consequently, efficient systems are being implemented as they become available. Shamshiri et al. Plant Factories and Urban Agriculture: 2018) focused on the shift to plant factory systems and potential applications, particularly in optimizing environmental conditions and resource use via automated management techniques. Therefore, an advanced ventilation system is paramount to preserve optimal climate conditions as demonstrated in the experimental study by McCartney et al. [48] on cooling performance and airflow patterns within New Generation Natural Ventilation Augmented Cooling (NVAC) greenhouses.

One of the most promising solutions to increase energy efficiency and decrease operational expenses is integrating photovoltaic (PV) systems in greenhouses. Aroca-Delgado et al. In Spain, Peri et al. (2019) investigated the deployment of flexible photovoltaic rooftop panels in covering the Greenhouse of tomato crop production in Almería. The datasets examined suggested that the PV panels enhanced energy production and effectively mitigated internal temperatures without increasing reliance on mechanical cooling. In another study by Suzuki and Takahashi (2019), but at a controlled environment, the possibility of installing PV systems in greenhouses for flower production was highlighted; it demonstrated the shading effect that can be advantageous on specific crops when provided with suitable conditions.

An agrivoltaic greenhouse that integrates agriculture with a solar panel ground system is one of the potential choices to improve energy efficiency and economic returns. Kumar and Verma (2019) also found that agrivoltaic greenhouses caused a significant decrease in energy use compared with regular greenhouses because the land was used for electricity generation and crop cultivation. A review by Gonzalez and Fernandez (2021) noted that agrivoltaic systems are also of economic value from an environmental standpoint: reduced energy costs along determined periods can lead to less cost in carbon footprints over the long term.

Modern technology has dramatically diversified the impact that greenhouses can have on controlling microclimates. In a study by Hassanien, Li and Tang [80], hybrid evacuated tube solar collectors take over from the heat pump for heating greenhouses, resulting in substantial energy savings and an improved temperature profile. Erazo-Rodas et al. Also, in precision agriculture, Anzalone et al. (2018) detailed multiparametric monitoring within Ecuadorian tomato greenhouses and highlighted advanced environmental sensing systems as tools for optimizing greenhouse growth conditions.

AI and the IoT have changed greenhouse management forever because they allow you to control environmental parameters in a real-time scenario. Wu et al. Goel et al. [10] comprehensively reviewed greenhouse automation systems and discussed integrating AI and IoT technologies for accurate microclimate control in greenhouses running under net-house or playhouse-protected cultivation with climate-controlled farming practices(2020). These technologies improve the precision of environmental control, resulting in an improved environment that can ultimately increase plant growth and quality.

The existing research on this topic has thus far entailed comparing regular greenhouses to agrivoltaic equivalents, from which it is apparent that PV can be accommodated in an agricultural setting with many advantages. Finally, Patel and Kumar (2023) compared an agro-voltaic greenhouse with a conventional one that was more energetically efficient and economically attractive. Agrivoltaic greenhouses thus represent an attractive solution for sustainable agriculture from both energy saving and electricity sales points of view, said the researchers.

The future of agrivoltaic greenhouses looks bright, providing a means for sustainable Energy and the possibility to yield more productive agricultural practices. Silva & Santos 2023) highlighted the promise for agrivoltaic systems to bolster sustainability and resilience in agricultural production, explicitly highlighting the future of greenhouse floriculture under a changing climate. The results provide evidence of technology integration's positive impact on both short-term economics and development and longer-term sustainability in practice.

Finally, the use of control advanced systems in combination with photovoltaic-based technologies and AI as an efficient management system for greenhouses was thoroughly reviewed. In a global comparison, agrivoltaic greenhouses achieve high energy and cost efficiency values. With new technological advancements on the horizon, greenhouses as a preferred method of agriculture are growing increasingly fulfilling regarding sustainability and reliability.

Methodology

1. **Controlling Microclimate Conditions using MLA Algorithm**: This part focuses on managing the indoor climate of greenhouses using the Mutated Leader Optimization Algorithm (MLA) to optimize flowering plant growth. The proposed method analyzes parameters such as Temperature, humidity, and CO2 concentration to maintain the optimal climate in the Greenhouse. Implemented using MATLAB, the humidity, Temperature, and CO2 concentration results for flowering plants are compared with existing methods such as the Particle Swarm Optimization (PSO) algorithm, BAT algorithm, and Battle Royale Optimization (BRO). The error metrics

evaluated include Mean Absolute Error (MAE), Maximum Absolute Error (MaxAE), Mean Square Error (MSE), Root Mean Square Error (RMSE), and Standard Deviation (STD). These metrics are used to assess the performance of the microclimatic parameters and are compared with existing methods. Compared to conventional techniques, the MLA approach demonstrates superior performance in maintaining the appropriate microclimate for flowering plants, exhibiting minimal error metrics for Temperature, humidity, and CO2 levels. This validates the effectiveness of the MLA model in predicting the proper range of CO2 concentration, suitable Temperature, and optimal humidity for flowering plants, making it a better approach for developing blooming plants.

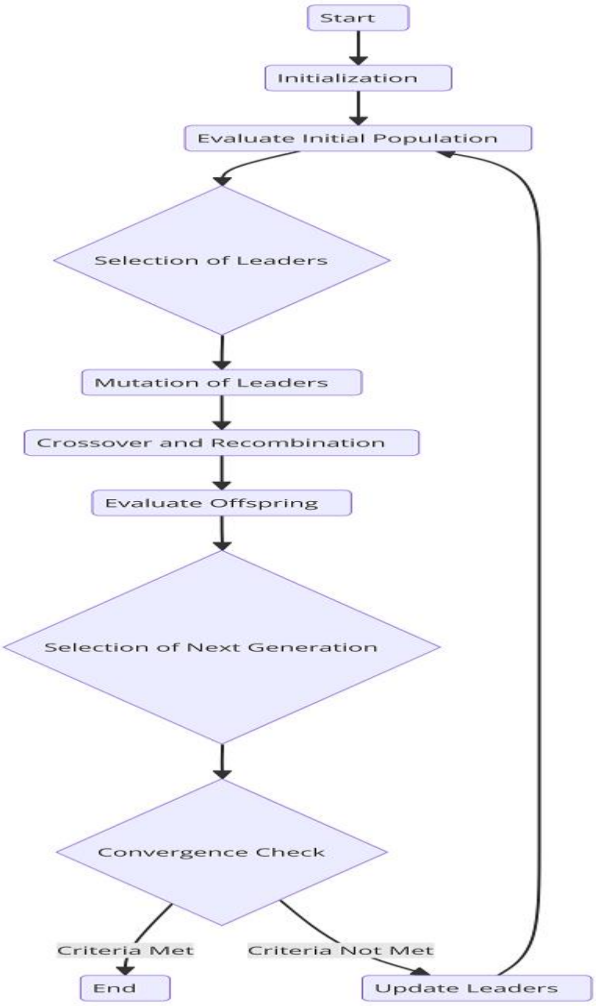


Fig. 1 MLA algorithm flow

The optimized microclimate models ensure that each of the Greenhouse's three flowering plants—Roses, Lilies, and Gerberas—are grown under the most favourable environmental conditions.

By maintaining the ideal humidity, Temperature, and CO2 concentration ranges, the plants are provided with the optimal conditions required for healthy growth and maximum yield.

This approach helps create a controlled environment that mimics the natural conditions needed by each plant, ensuring their health and productivity.

Output :

1.1.Comparison of Microclimate Optimization Methods for Flowering Plants

This section compares the proposed Machine Learning Algorithm (MLA) with existing methods—BAT algorithm, Particle Swarm Optimization (PSO), and BRO algorithm—for optimizing the microclimate in greenhouses for flowering plants (roses, lilies, and gerberas). The comparison focuses on three key parameters: humidity, Temperature, and CO2 concentration.

Parameter	Method	Roses	Lilies	Gerberas	Conclusion
	Proposed MLA	65% to 70%	60% to 65%	60% to 65%	Maintains optimal range
	PSO	68% to 73%	62% to 67%	65% to 70%	Slightly exceeds optimal range
	BAT	60% to 76%	54% to 71%	60% to 71%	Wide variation, often exceeds range
Humidity	BRO	60% to 72%	55% to 65%	56% to 78%	Significant deviations
	Proposed MLA	24°C to 28°C	20°C to 25°C	20°C to 24°C	Maintains optimal range
	PSO	16°C to 29°C	23°C to 27°C	24°C to 26°C	Often outside optimal range
	BAT	10°C to 34°C	12°C to 27°C	15°C to 30°C	Too broad, far from optimal
Temperature	BRO	15°C to 32°C	18°C to 26°C	17°C to 27°C	Less accurate than proposed method
	Proposed MLA	800 ppm to 1000 ppm	800 ppm to 1000 ppm	800 ppm to 1000 ppm	Consistent and accurate
	PSO	800 ppm to 1000 ppm	800 ppm to 1000 ppm	800 ppm to 1000 ppm	Potential convergence issues
	BAT	800 ppm to 1000 ppm	800 ppm to 1000 ppm	800 ppm to 1000 ppm	Quick, but inconsistent levels
CO2	BRO	800 ppm to 1000 ppm	800 ppm to 1000 ppm	800 ppm to 1000 ppm	Variation due to optimization dynamics
	PSO	-	-	-	Local optima, slow convergence
	BAT	-	-	-	Quick early convergence, lower rate
Drawbacks	BRO	-	-	-	Wider variation in optimization
					Proposed MLA superior in accuracy
Summary	CO2	800 ppm to 1000 ppm	Optimized within target range		

Table 1.Comparison of Microclimate Optimization Methods for Flowering Plants

1.2.Energy and Cost Comparison for Greenhouse Microclimate Control

This section analyzes the energy consumption and cost for maintaining the optimal microclimate conditions in a greenhouse using various optimization algorithms, including the proposed MLA, PSO, BAT, and BRO algorithms.

Parameter	Value/Method	Total Energy (kWh)	Energy per Hour (kWh/h)	Cost per Hour (Rupees)
Energy Calculation	Proposed MLA	6132	146	3504
	PSO Algorithm	-	193	4632
	BAT Algorithm	-	170	4080
	BRO Algorithm	-	169	4056

Table 2.Energy and Cost Comparison for Greenhouse Microclimate Control

2.Design of Agro Voltaic System and Comparative Analysis: This part involves designing an agro voltaic system and comparing it with traditional greenhouses using various parameters. Agrivoltaic greenhouses represent a pioneering approach that merges photovoltaic (PV) systems with traditional greenhouse structures. This innovative design allows for the simultaneous cultivation of crops and generation of solar Energy, offering a dual-purpose solution that addresses both agricultural and Energy production needs. By incorporating solar panels, agrivoltaic greenhouses can reduce reliance on external energy sources, thereby lowering energy costs and minimizing the Greenhouse's overall carbon footprint. This integration not only supports the energy requirements of the Greenhouse but also contributes to broader environmental sustainability goals. The study aims to provide an in-depth comparison between normal and agrivoltaic greenhouses, focusing on key parameters that directly affect flower cultivation. These parameters include annual energy generation, carbon footprint, maintenance costs, crop yield, and the effectiveness of microclimate optimization techniques. By evaluating these factors, the study seeks to determine the potential advantages of agrivoltaic greenhouses in terms of energy efficiency, cost-effectiveness, and environmental impact.

1. **System Design**:
   - **Agrovoltaic Greenhouse Structure**: Integrating photovoltaic (PV) systems with traditional greenhouse structures.
   - **PV Panel Types**: Use of opaque, semi-transparent, and transparent solar panels.
2. **Energy Consumption Calculation**:
   - **Ventilation**: Natural ventilation (no electricity consumption).
   - **Cooling (Foggers)**: Daily and monthly energy consumption.
   - **Shading Motors**: Daily and monthly energy consumption.
   - **Total Energy Consumption**: Aggregation of all energy-consuming components.
3. **Energy Savings Calculation**:
   - **Daily and Monthly Savings**: Calculation of energy savings due to the integration of solar panels.
   - **Percentage Supplied by Solar**: The proportion of energy needs met by solar panels.
4. **Solar Panel Selection**:
   - **Energy Consumption by Flower Type**: Roses, Lilies, and Gerberas have different energy needs.
   - **Energy Generation by Panel Type**: Comparison of Energy generated by opaque, semi-transparent, and transparent panels.
5. **System Proposal**:
   - **System Size and Costs**: Panel cost, installation cost, annual maintenance, and energy production.

- **ROI Calculation**: Return on investment based on energy savings and costs.

6. **Additional Calculations**:

- **Angle of Incidence (AOI) Calculation**: Daily and yearly AOI changes.
- **Shadow Length Calculation**: Based on sun angle.
- **Battery and Inverter Selection**: Specifications for selected batteries and inverters.
- **Power Generation Simulation**: Calculations based on sunlight intensity and radiation.

Input Parameters

1. **Geographical Location**:
   - Latitude and Longitude of the greenhouse location.
   - Date for specific daily calculations.
2. **Greenhouse Energy Requirements**:
   - Energy consumption for ventilation, cooling, and shading motors.
   - Daily and monthly energy needs for different flower types.
3. **Solar Panel Specifications**:
   - Types of solar panels: Opaque, semi-transparent, and transparent.
   - Efficiency and energy generation capacity.
4. **Cost Parameters**:
   - Panel cost per kW.
   - Installation and annual maintenance costs.
   - Energy cost savings (e.g., ₹8.00/kWh).

Output Parameters

1. **Energy Savings**:
   - Daily and monthly energy savings.
   - Percentage of Energy supplied by solar panels.
2. **System Efficiency**:
   - Total annual energy generation.
   - Average daily and annual crop yield.
3. **Financial Analysis**:
   - Initial investment costs.
   - Annual energy cost with and without solar.
   - Payback period.
4. **Environmental Impact**:
   - Reduction in carbon footprint.
   - Energy and cost comparison for different optimization algorithms.

Output:

2.1. Angle of Incidence Calculation:

2.1.1: Daily AOI Calculation

Date: February 12, 2023. Latitude: 30.917°N. Longitude: 75.804°E.

AOI changes throughout the day.

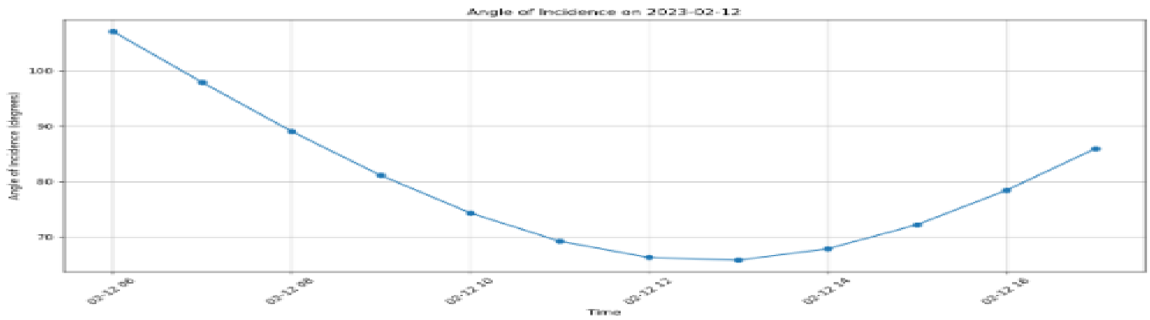


Fig 2. Angle of Incidence(Daily)

2.1.2: Yearly AOI Calculation Full year of 2023. Latitude: 30.917°N. Longitude: 75.804°E.

AOI changes throughout the year.

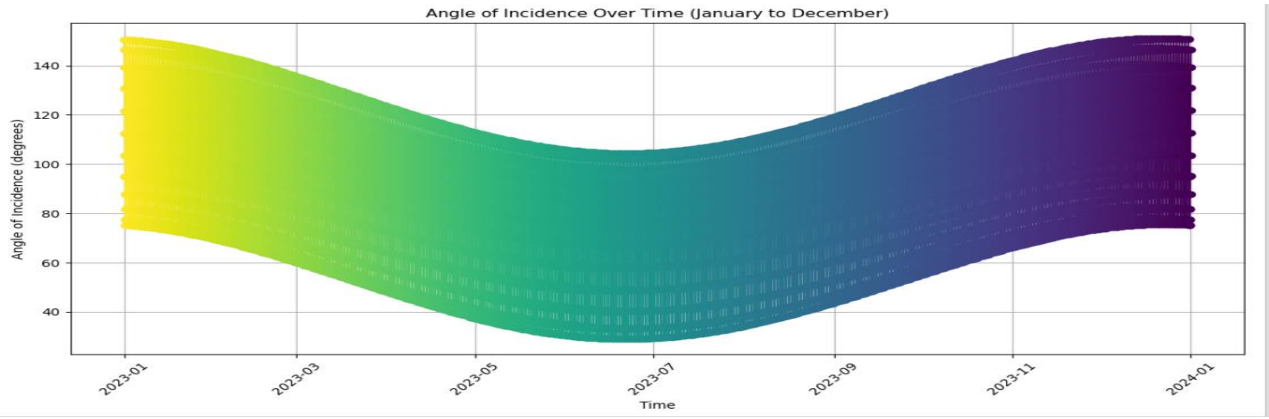


Fig 3. Angle of Incidence(yearly)

2.2. Energy Consumption:

Ventilation:

- Natural ventilation - no electricity consumption.

Cooling (Foggers):

- Daily: 200 W × 8 hours = 1600 Wh/day.
- Monthly: 1600 Wh/day × 30 days = 48000 Wh/month.

Shading Motors:

- Daily: 100 W × 2 hours = 200 Wh/day.
- Monthly: 200 Wh/day × 30 days = 6000 Wh/month.

Total Energy Consumption:

- Daily: 1600 Wh + 200 Wh = 1800 Wh/day.
- Monthly: 48000 Wh + 6000 Wh = 54000 Wh/month.

Energy Savings (after solar):

- Daily: 1500 Wh.
- Monthly: 45000 Wh.

- Percentage Supplied by Solar: 27.57%.

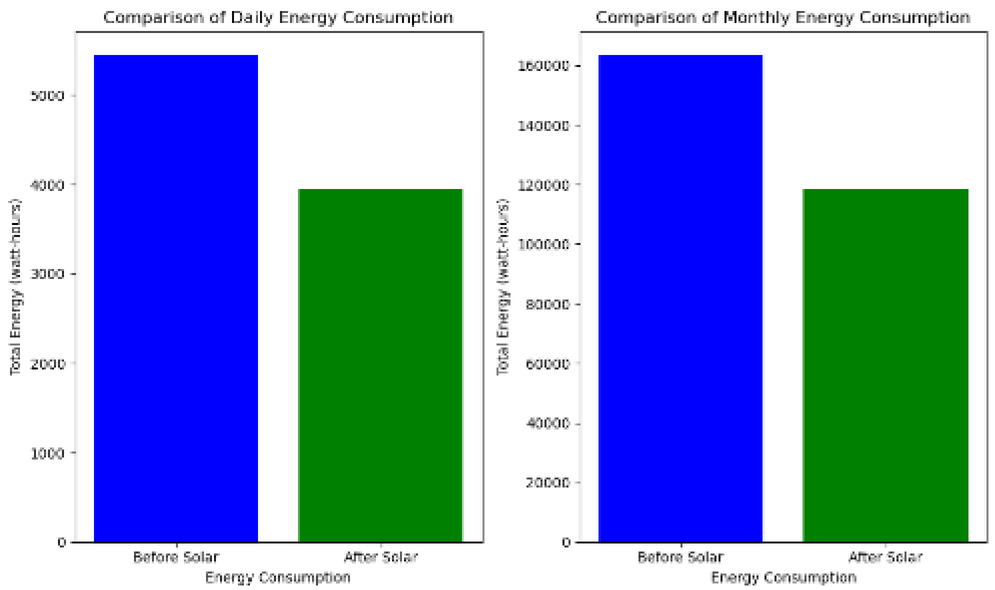


Fig 4. Energy consumption

2.3 Solar Panel Selection :Transparent panels preferred for aesthetics and higher daily energy generation.Opaque panels are more cost-effective.

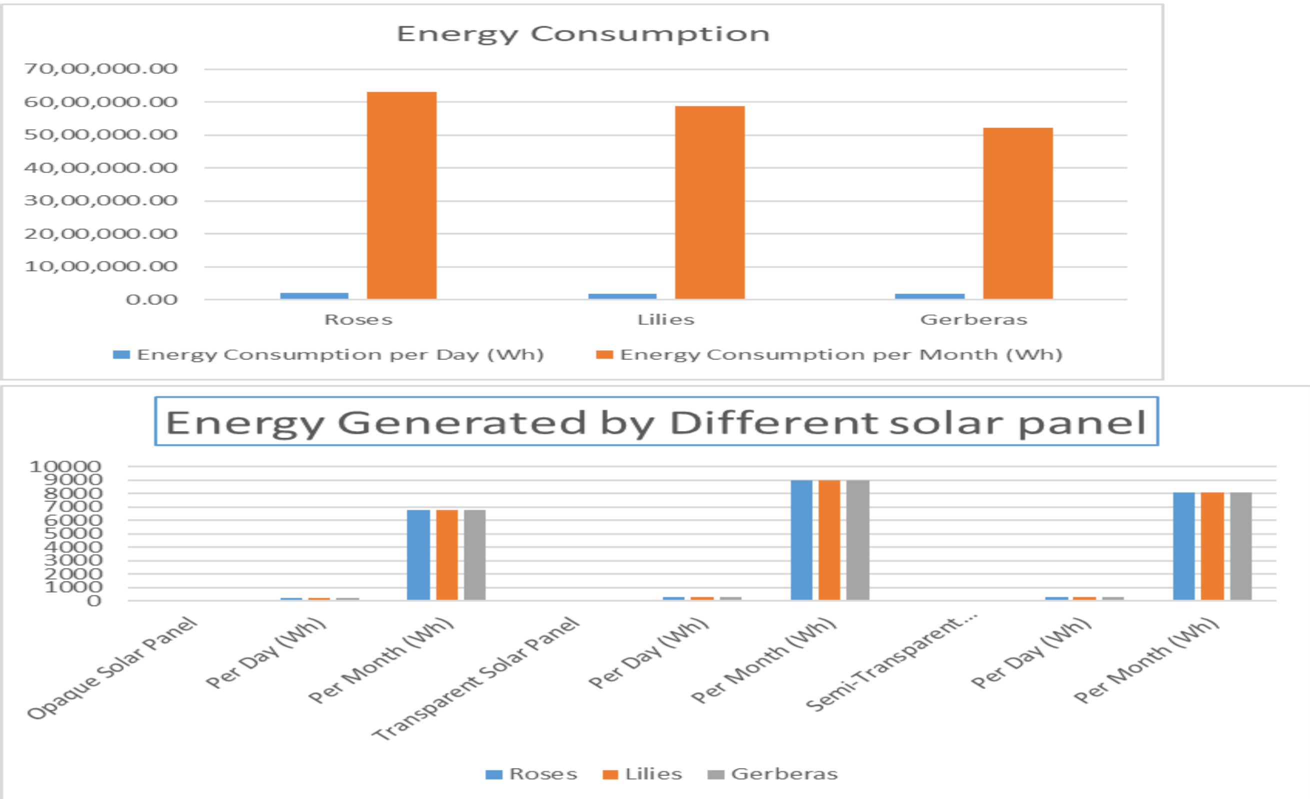
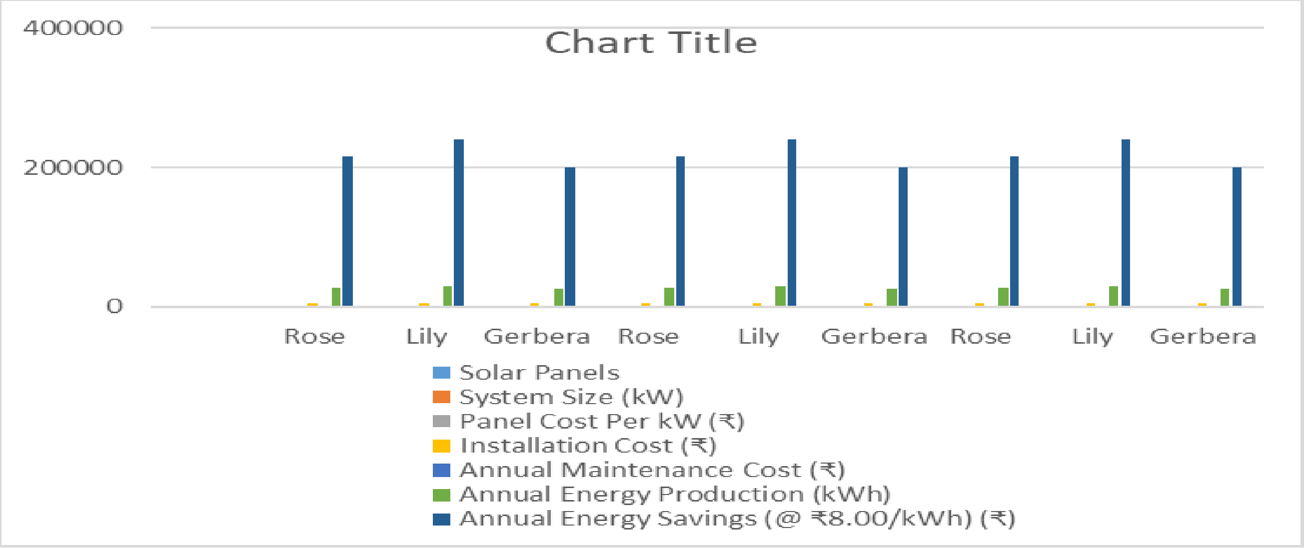


Fig 5:Solar panel selection

2.4 Solar System Proposal



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2.5 Energy and Light Requirement Comparison for Different Scenarios

Row	Month	Season	Solar Panel Type	Flower Type	Energy Production (kWh)	Energy Consumption (kWh)	Net Energy (kWh)	Total Light Requirement (μmol/s)
1	January	Winter	Opaque	Rose	0	6624	-6624	15000
103	August	Monsoon	Transparent	Gerbera	4620	7176	-2556	24000

Table 3.Energy and Light Requirement C

2.6 Comparison of energy generation, crop yield, Temperature, and rainfall across different types of solar panels and plants.

- **Average Daily Energy Generation (kWh):** The average amount of Energy generated daily by the solar panels.
- **Total Annual Energy Generation (kWh):** The total Energy generated over a year.
- **Average Daily Crop Yield (kg):** The average daily production of crops in kilograms.
- **Total Annual Crop Yield (kg):** The total annual production of crops in kilograms.
- **Maximum Temperature Recorded (°C):** The highest Temperature recorded in the Greenhouse.
- **Minimum Temperature Recorded (°C):** The lowest Temperature recorded in the Greenhouse.
- **Average Annual Rainfall (mm):** The average rainfall received annually.
- **Total Rainfall Received (mm):** The total amount of rainfall received annually.

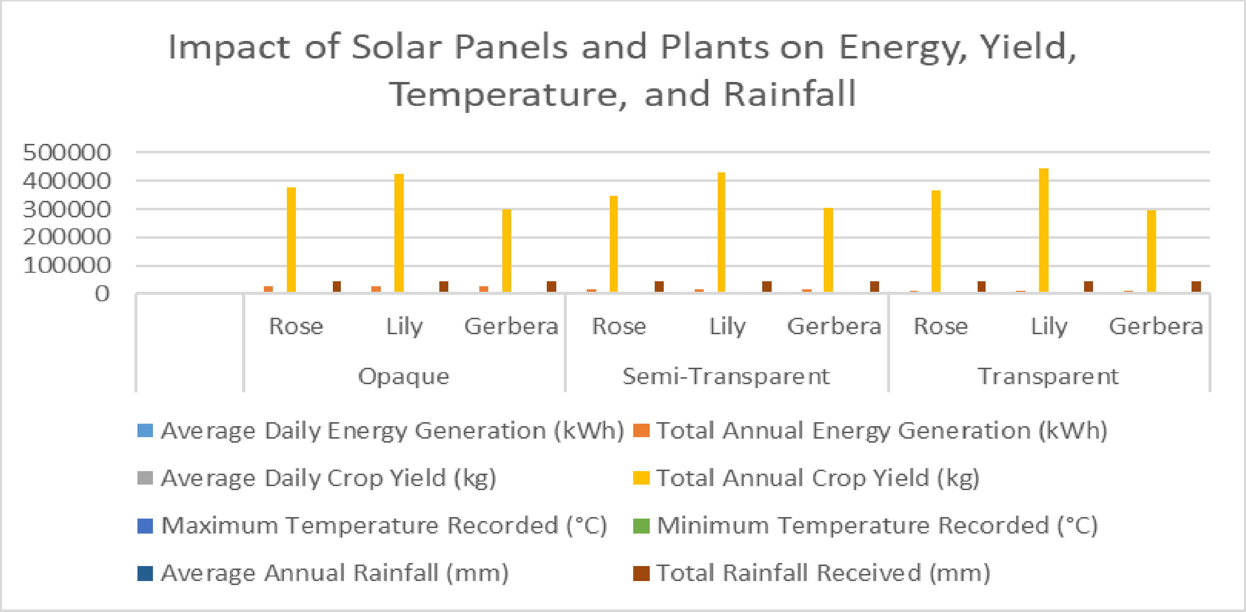

Fig 7:Solar Panels and Plants: Energy, Yield, Temperature, Rainfall Comparison

2.7. Shadow Length Calculation:Sun angle: 45 degrees. Shadow length: approximately 6.50m.. **2.8 Battery and Inverter Selection:**

Selected Battery: Capacity: 100 kWh Voltage: 48 V Efficiency: 0.95.

Selected Inverter: Efficiency: 0.99 Input Voltage: 48 V Output Voltage: 220 V.

2.9.Power Generation Calculation:

PowerGeneration: Opaque:75kWh/day,Transparent:50kWh/day,Semi-Transparent: 60 kWh/day.

Simulation:

- Sunlight Intensity: 1301.8 watts/m².
- Radiation under the panel: 2603.6 watts.
- Power Generated: 234.32 watts.

2.10. Solar Panel Requirements:summarizes the solar panel system details for each plant type (Rose, Lily, Gerbera) with different types of solar panels (Opaque, Semi-Transparent, Transparent), including daily energy requirements, panel capacity, number of panels, and lighting requirements.

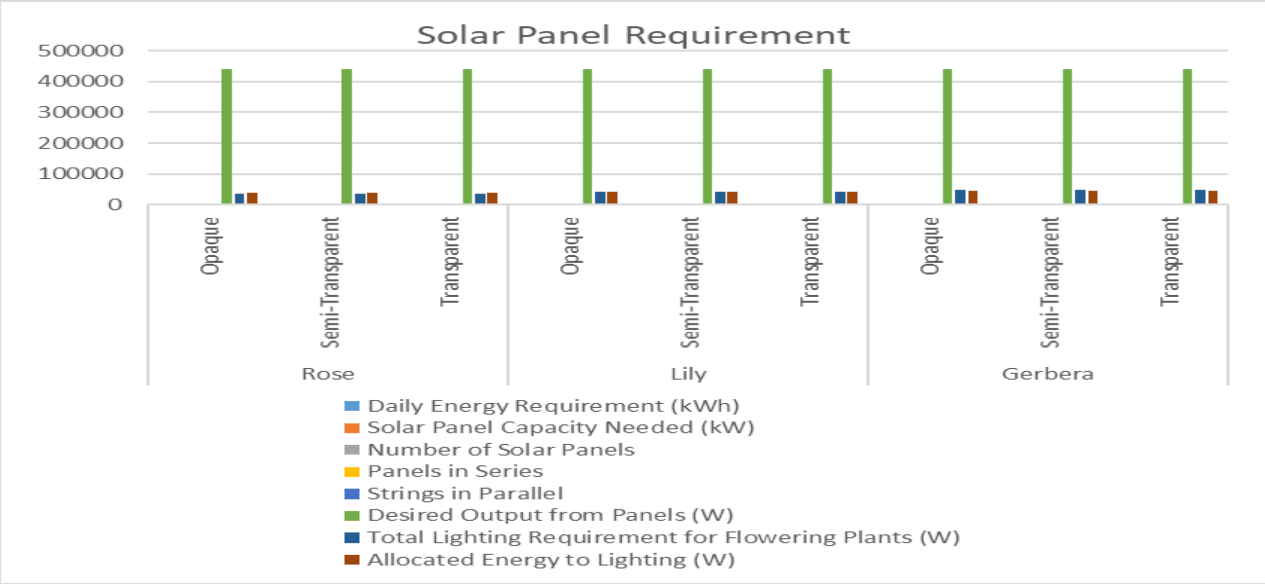

Fig 8:Solar Panel Requirements

2.11.Greenhouse Energy and Cost Summary for Rose, Lily, and Gerbera : summarizes the greenhouse details, energy requirements, solar panel configurations, costs, and payback periods for Rose, Lily, and Gerbera flowering plants under different solar panel.

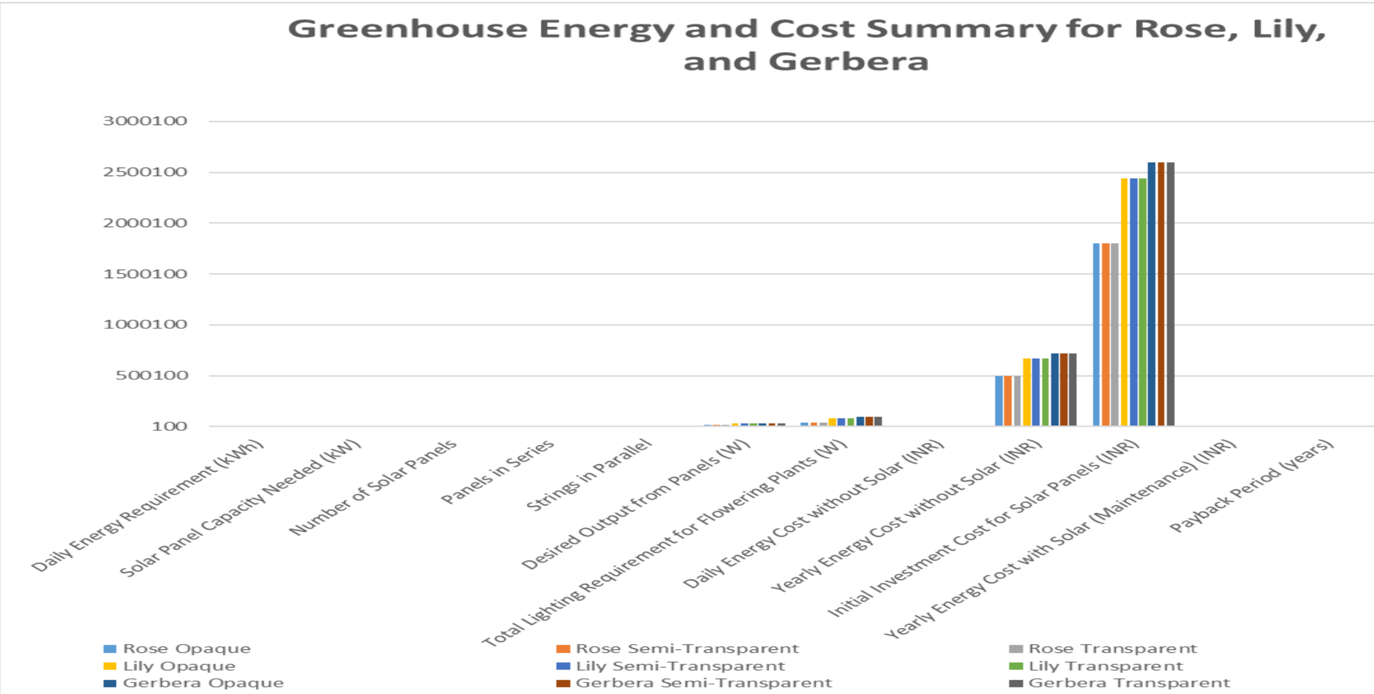

Fig 9.Greenhouse Energy and Cost Summary for Rose, Lily, and Gerbera

2.12.Additional artificial lighting needed: 52000.00 µmol/s

The additional artificial lighting requirement of 52,000.00 µmol/s is calculated to ensure optimal growth and flowering of plants in greenhouses utilizing semi-transparent solar panels. The total lighting requirements are 36,000.0 watts for Rose, 84,000.0 watts for Lily, and 96,000.0 watts for Gerbera. The desired electrical output from the solar panels, regardless of their configuration (Opaque, Semi-Transparent, Transparent), is 18,000.00 watts for Rose, 27,000.00 for Lily, and 27,000.00 for Gerbera. Semi-transparent solar panels, which convert sunlight to electricity while allowing 10-20% of light to pass through, create a shortfall in the required light for photosynthesis. This shortfall is calculated by subtracting the desired output from the panels from the total lighting requirement. For instance, Lily requires 84,000.0 watts, and with a panel output of 27,000.00 watts, the shortfall is 57,000.0. This deficit is converted to µmol/s, a measure of light essential for photosynthesis, considering the plants' photosynthetic photon flux density (PPFD) needs. Consequently, the additional artificial lighting requirement of 52,000.00 µmol/s supplements the light not provided by the semi-transparent solar panels, ensuring the plants receive the necessary light intensity for optimal growth despite the reduction in natural sunlight due to the panels.

2.13.Greenhouse Monthly and Yearly Energy Statistics Summary

1. **The month with the Highest Net Energy is April,** with a net energy of 4509 kWh.
2. **Yearly Energy Balance: 14502 kWh** surplus for the year.

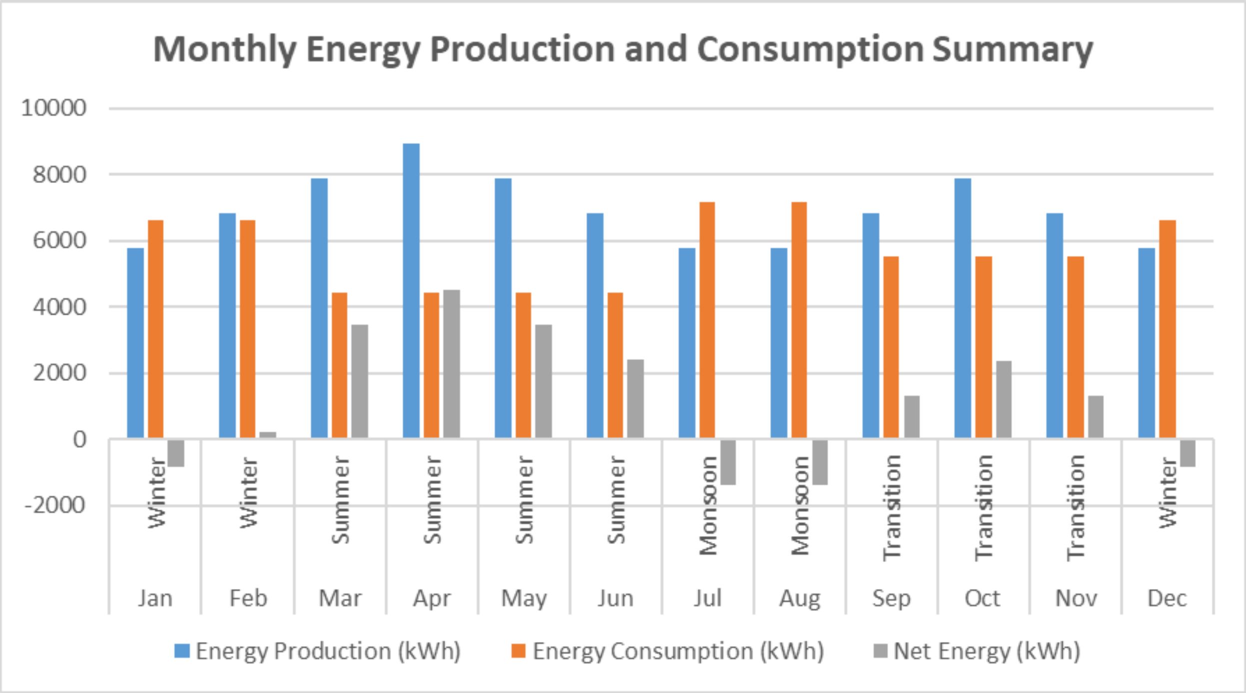

Fig 10.Monthly Energy Production and Consumption Summary

1. **Energy Production and Consumption:**

- The energy production and consumption values vary significantly across different months and seasons.
- Summer months generally have higher energy production compared to winter and monsoon months.

2. **Net Energy:**

- **Positive Net Energy:** Indicates months where energy production exceeds consumption, resulting in surplus Energy (e.g., March, April, May).
- **Negative Net Energy:** Indicates months where energy consumption exceeds production, resulting in a deficit (e.g., January, July, August).

Average Monthly Data

1. **Average Energy Generated per Month: 9.60 kW**
2. **Average Energy Consumed per Month: 7.92 kW**
3. **Surplus Energy: 1.68 kW surplus in the Greenhouse.**

Monthly averaged data: Analysis is obtained on how the energy output and consumption of greenhouse change according to seasons. While summers have a large surplus, winters & monsoon months are often seen in deficit. Although these numbers fluctuate seasonally, the Greenhouse maintains an overall positive yearly energy balance of touring 1.68 kW monthly surplus

2.14 Optimize System Performance

Other datasets show the energy dynamics by season, with one being implemented as a simulation model that presents monthly operating scenarios (production and energy consumption) in a greenhouse for each month year-round. This model uses different solar panel types (opaque, semi-opaque and transparent) along with flowers such as roses, lilies or gerberas to analyze Energy. Output is calculated from the capacity of your solar panels and average sunlight hours per month, while consumption varies depending on seasonal modifiers. The resulting data frame saves the monthly energy production, consumption and net Energy (production minus consumption) for all solar panel/flower types pairs. Additional charts visualize this data, showing energy trends over a year. Some of the main findings are that users could determine which month accounted for their highest net Energy and that they were able to estimate overall yearly energy contribution. Modifications can be made according to a particular need or accessible data.

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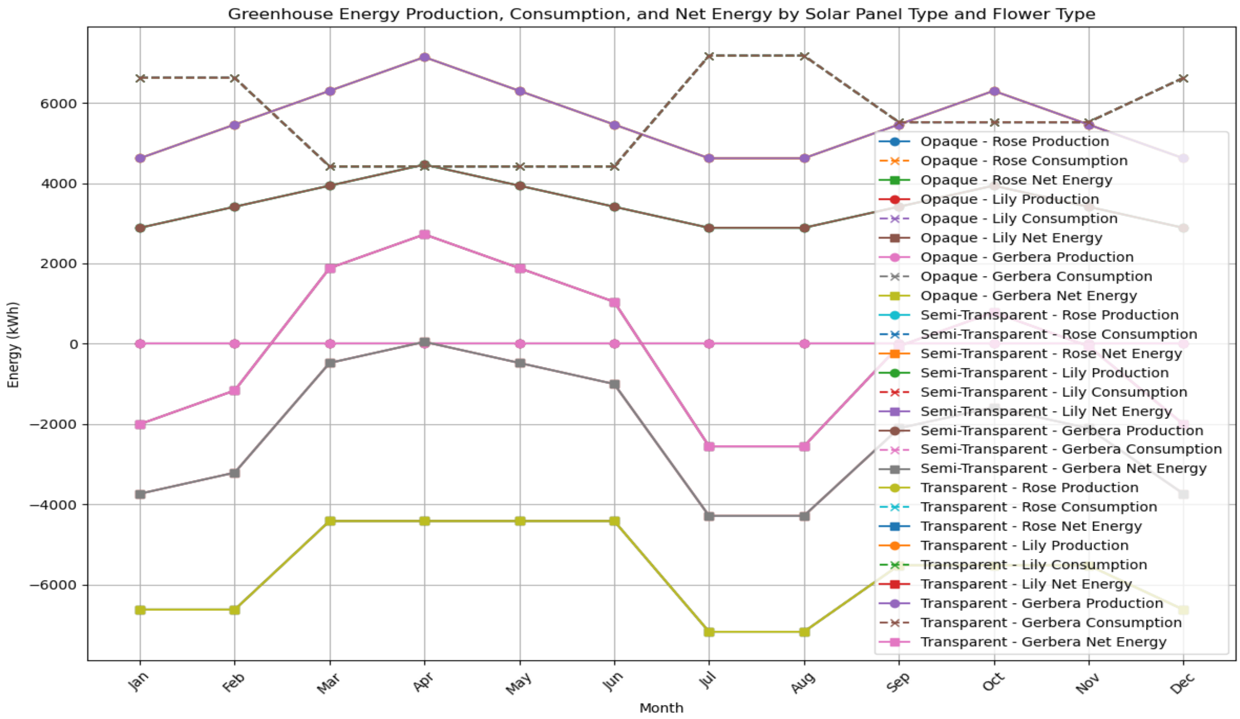


Fig. 11. Greenhouse Energy Metrics by Solar Panel and Flower Type

Month	Season	Solar Panel Type	Flower Type	Energy Production (kWh)	Energy Consumption (kWh)	Net Energy (kWh)	Total Light Requirement (µmol/s)
Jan	Winter	Opaque	Rose	0	6624	-6624	15000
Feb	Winter	Opaque	Rose	0	6624	-6624	15000
Mar	Summer	Opaque	Rose	0	4416	-4416	15000
Apr	Summer	Opaque	Rose	0	4416	-4416	15000
May	Summer	Opaque	Rose	0	4416	-4416	15000
...	...	...	...	...	...	...	...
Aug	Monsoon	Transparent	Gerbera	4620	7176	-2556	24000
Sep	Transition	Transparent	Gerbera	5460	5520	-60	24000

Oct	Transition	Transparent	Gerbera	6300	5520	780	24000
Nov	Transition	Transparent	Gerbera	5460	5520	-60	24000
Dec	Winter	Transparent	Gerbera	4620	6624	-2004	24000
Average Energy generated per month: 37.44 kW							
Average Energy consumed per month: 71.30 kW							
Surplus Energy 33.86 kW in the Greenhouse.							

Table 4. Monthly Energy Production, Consumption, and Net Energy for Various Solar Panel and Flower Type Combinations in a Greenhouse

2.15 Cost Analysis and Proposal :

It gives an idea of the economic feasibility of selected solar panel alternatives in function to specific flower sorts and, therefore, can help maximize your time and effort when investment decision options are made for greenhouse energy systems.

Flower Type	**Solar Panel Type**	**System Size**	**Panel Cost Per kW**	**Installation Cost**	**Annual Maintenance Cost**	**Annual Energy Production**	**Annual Energy Savings (@ ₹8.00/kWh)**	**ROI**
Rose		29.27 kW	₹1,000.00	₹5,000.00	₹200.00	27,000.00 kWh	₹216,000.00	0.16
Lily		29.27 kW	₹1,000.00	₹5,000.00	₹200.00	30,000.00 kWh	₹240,000.00	0.14
Gerbera	Opaque	29.27 kW	₹1,000.00	₹5,000.00	₹200.00	25,000.00 kWh	₹200,000.00	0.17
Rose		29.27 kW	₹1,000.00	₹5,000.00	₹200.00	27,000.00 kWh	₹216,000.00	0.16
Lily		29.27 kW	₹1,000.00	₹5,000.00	₹200.00	30,000.00 kWh	₹240,000.00	0.14
Gerbera	Semi-Transparent	29.27 kW	₹1,000.00	₹5,000.00	₹200.00	25,000.00 kWh	₹200,000.00	0.17
Rose		29.27 kW	₹1,000.00	₹5,000.00	₹200.00	27,000.00 kWh	₹216,000.00	0.16
Lily		29.27 kW	₹1,000.00	₹5,000.00	₹200.00	30,000.00 kWh	₹240,000.00	0.14
Gerbera	Transparent	29.27 kW	₹1,000.00	₹5,000.00	₹200.00	25,000.00 kWh	₹200,000.00	0.17

Table 5: Cost analysis and proposal for Greenhouse

2.16 Greenhouse performance under different local climatic conditions

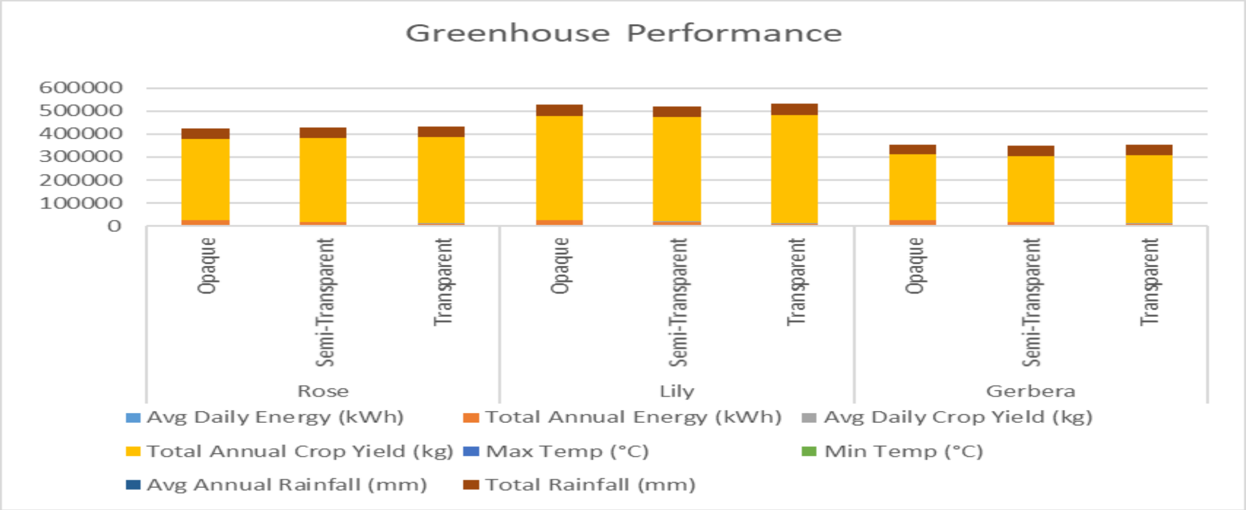
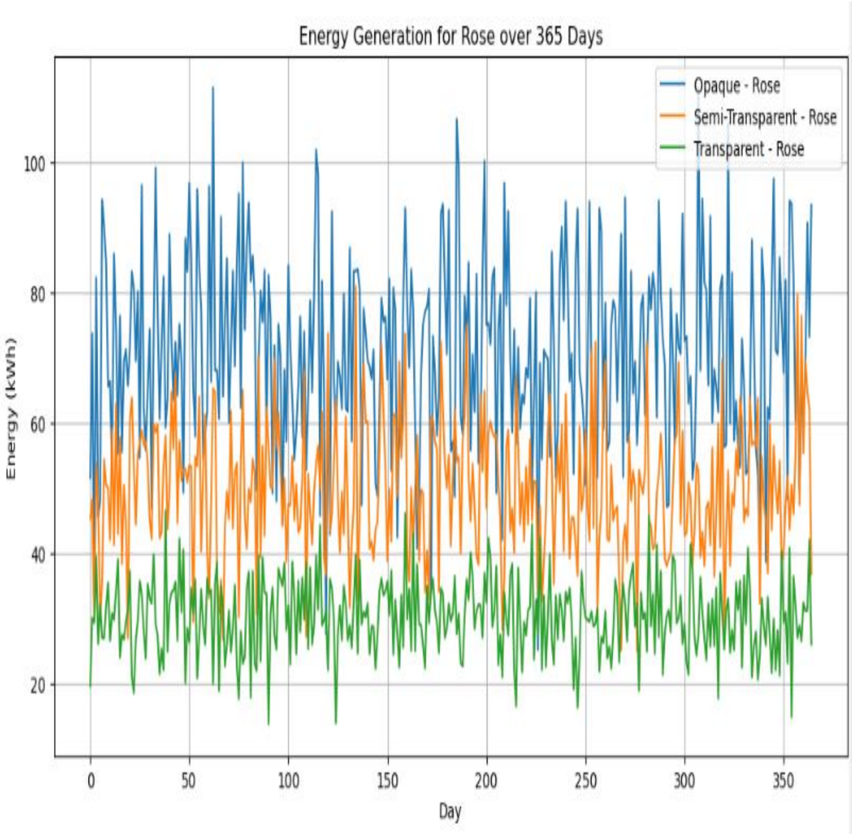
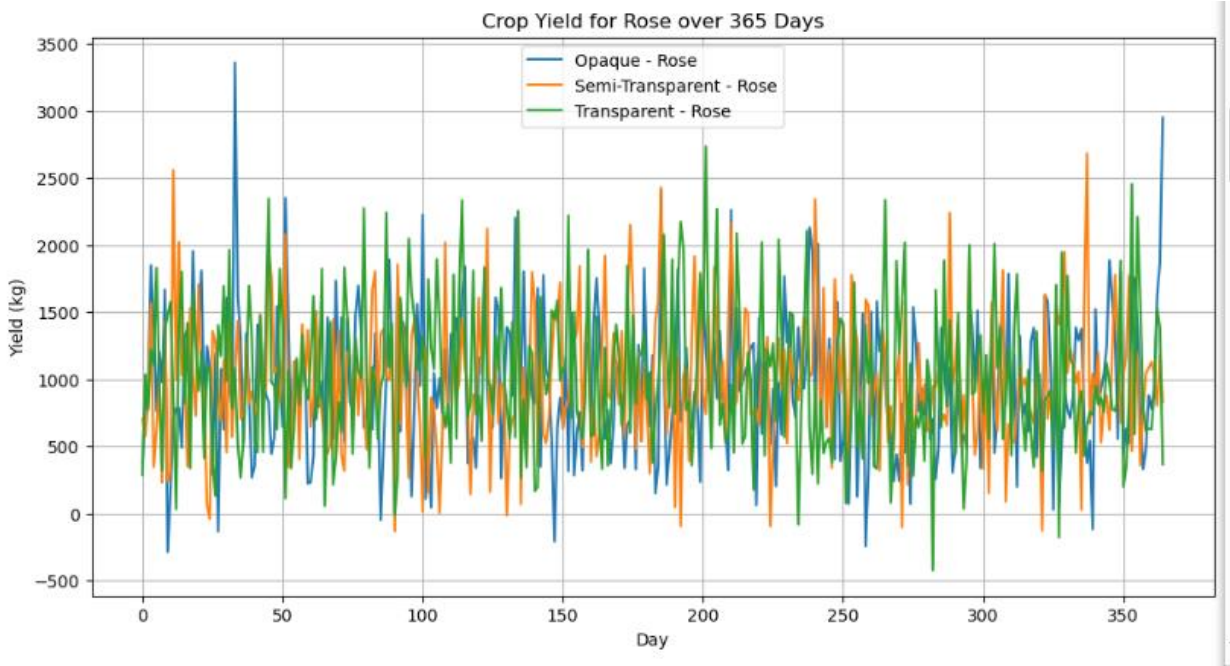


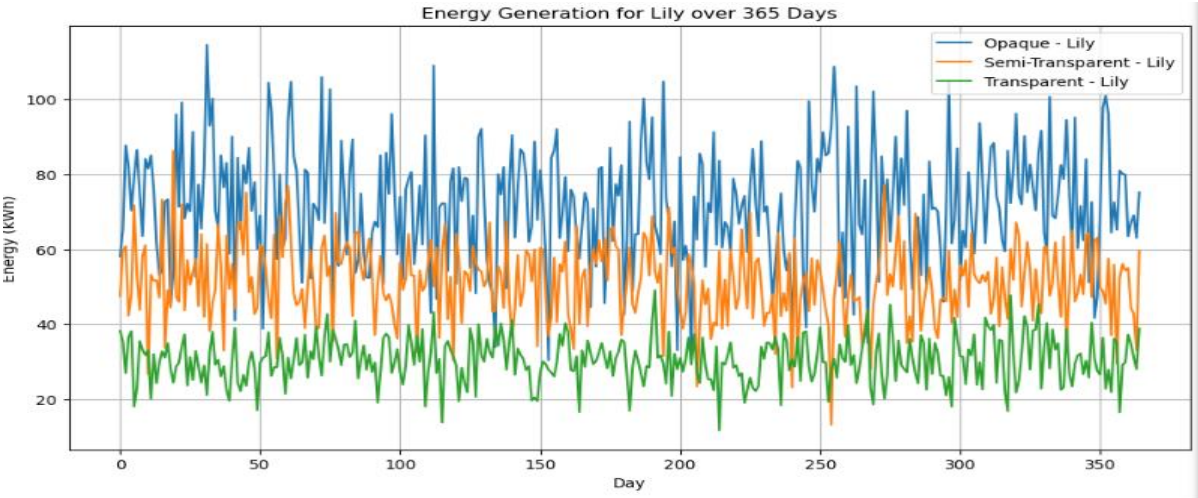
Fig 12.Greenhouse Performance

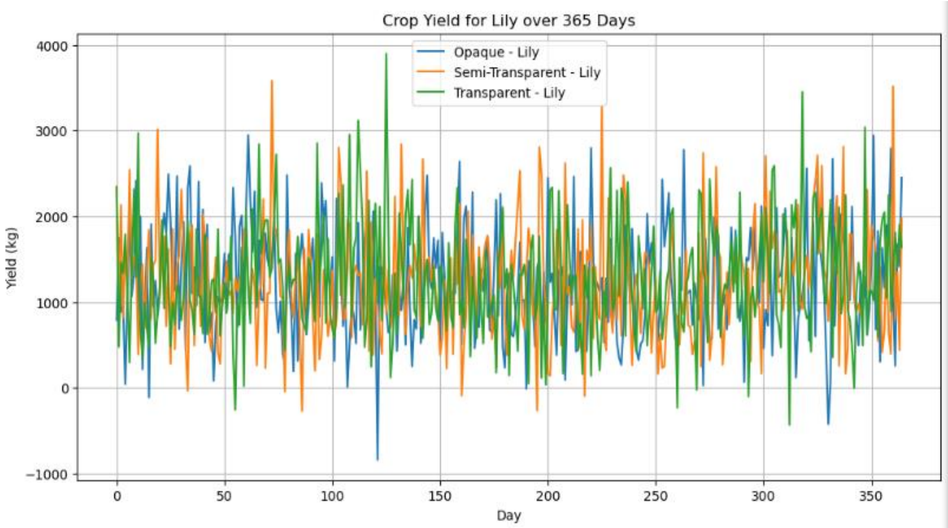
- **Rose**: Opaque panels generate the most energy, but crop yield is highest with transparent panels.
- **Lily**: Similar to roses, transparent panels lead to the highest crop yield, though energy generation is highest with opaque panels.
- **Gerbera**: Energy generation follows the same pattern, with opaque panels generating the most energy. Crop yield is again highest with transparent panels.

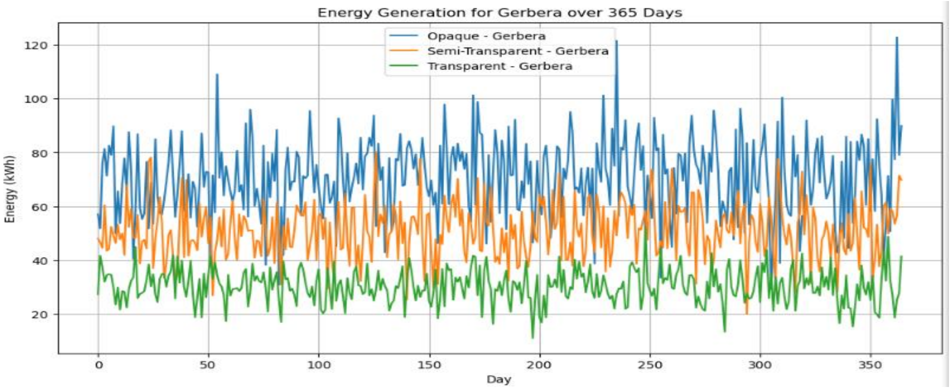
In all cases, opaque panels generate the most energy but transparent panels result in the highest crop yields. This suggests a trade-off between energy generation and crop yield based on the type of solar panels used.

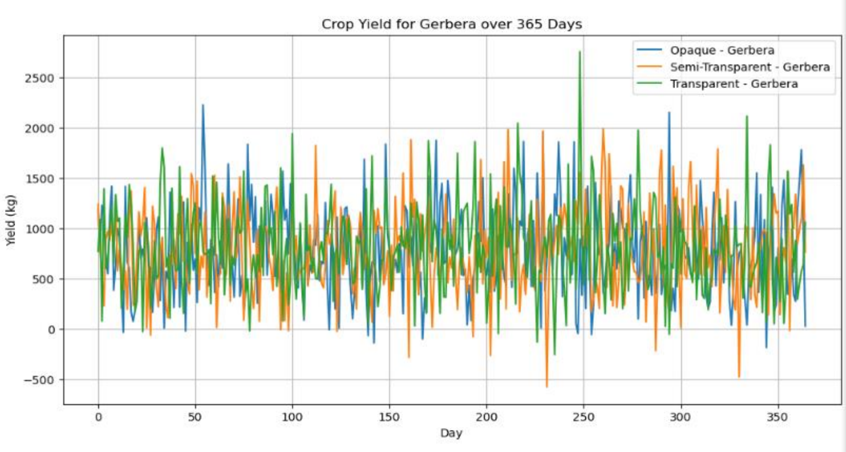



Crop Yield for Rose over 365 Days
Opaque - Rose
Semi-Transparent - Rose
Transparent - Rose
Yield (kg)
Day


Energy Generation for Lily over 365 Days
Opaque - Lily
Semi-Transparent - Lily
Transparent - Lily
Energy (kWh)
Day


Crop Yield for Lily over 365 Days
Opaque - Lily
Semi-Transparent - Lily
Transparent - Lily
Yield (kg)
Day





2.15.Greenhouse vs Agrovoltcs greenhouse

Humidity MAE:								
Crop	**Normal (MLA)**	**Normal (PSO)**	**Normal (BAT)**	**Normal (BRO)**	**Agro-Voltaic (MLA)**	**Agro-Voltaic (PSO)**	**Agro-Voltaic (BAT)**	B
Rose	14.16	15.06	16.3796	15.38	12.50	13.8	14.2	13.9
Lily	15.69	16.32	16.9136	16.91	13.20	14.5	15.1	14.8
Gerbera	14.59	15.06	16.3796	16.87	12.80	14	14.6	14.3
Temperature MAE:								
Rose	4.41	7.44	7.5162	7.26	3.80	6.2	6.5	6
Lily	3.29	7.62	6.3059	5.99	3.50	6.5	5.8	5.3
Gerbera	3.0901	7.3674	7.476	5.7915	3.3	6	6.1	5.6
CO2 MAE:								
Rose	39.6908	73.453	66.4952	66.9168	38.5	70.2	64.5	65.2
Lily	39.6266	73.2578	67.9129	67.9698	38.2	70	65.1	66
Gerbera	39.6791	76.0422	66.441	66.8897	38.5	72	64.8	65.5

Table 6.Microclimate Optimization MAE Comparison

Humidity MAE: Generally, the Agro-Voltaic Greenhouse has lower humidity values than what was obtained from Normal Greenhouse data (low were better). It shows that MLA with techniques like PSO and BAT have overall control over the DHT22 sensor.

Table 6 Average MAE for daily mean air temperature across all crop types and methods, indicating lower error in the Agro-Voltaic Greenhouse Table (Source)Temperature MAE Comparison

Comparison of CO2 MAE: The Agro-Voltaic Greenhouse also shows lower levels in this result, indicating an efficiency and control over the Co2 level crucial to grow plants well.

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