 DOI: 10.22616/RRD.31.2025.021

THE INFLUENCE OF GREENHOUSE INTEGRATED PHOTOVOLTAICS ON MICROCLIMATE

***Arturs Lozbergs[1,2], Liene Kancevica[2], Kaspars Vartukapteinis[2]**
[1]Institute of Agricultural Resources and Economics, Latvia
[2]Latvia University of Life Sciences and Technologies, Latvia
*Corresponding author's e-mail: arturs.lozbergs@gmail.com

Abstract
The utilization of photovoltaics (PVs) has proven to be a remarkably effective solution in a diverse range of domestic and industrial contexts. The integration of roof surfaces with PV systems has facilitated the generation of clean, renewable electricity, thereby addressing critical concerns regarding energy sustainability and environmental impact. Photovoltaic greenhouses constitute hybrid systems, integrating photovoltaic technology with conventional agricultural practices within a single space. Furthermore, this particular type of greenhouse retains all the characteristics of a conventional greenhouse, whilst simultaneously offering the possibility of electricity production. The purpose of this study is to evaluate the impact of the shading caused by photovoltaic panels on the microclimate, with specific reference to air temperature and relative humidity. The experiment was conducted in two similar greenhouses. Bifacial photovoltaics were installed on the entire roof surface of one greenhouse, while the other greenhouse, which was uniformly shaded by a polycarbonate sheet, served as a control greenhouse. The results illustrate that, despite the negligible immediate effect of photovoltaics, a comparison with findings from other scientific studies clearly indicates that photovoltaics can contribute to the improvement of greenhouse microclimate, including in the Nordic countries of the Baltic States. Moreover, it has been demonstrated that photovoltaic technology has the capacity to serve not only as a source of energy but also as a constructive element in greenhouse systems.
Keywords: photovoltaics, microclimate, greenhouse, humidity, shading.

Introduction

Greenhouse cultivation is a contemporary agricultural technology that provides an optimal microclimate conducive to the growth of crops. Such a climate is characterized by specific factors such as relative humidity, lighting, and ambient air temperature, which are collectively or separately influential on the cultivation of specific crops and the timing of their yield. The application of this technology is especially relevant in contexts involving out-of-season cultivation (Lu et al., 2020). Consequently, agrivoltaic systems have come to the fore as a potential solution to mitigate the competing demands on land usage that arise from the deployment of photovoltaic (PV) technology and agricultural activities (Fernández et al., 2022). Moreover, greenhouses are typically constructed in areas characterized by ample sunlight exposure. This is due to the necessity of sunlight for the process of photosynthesis in plants. Consequently, such locales are inherently conducive to the generation of photovoltaic energy (Zhao et al., 2021).

One such area of interest is the development of urban areas through the establishment of urban gardens. This approach could be demonstrated to enhance the quality of sustainable urban environments and promote food self-sufficiency. Furthermore, it could help increase independence from electricity prices and power outages by utilizing the same area.

Photovoltaic energy can thus be considered as renewable, sustainable, clean and available. It is evident that the utilization of this energy is on the rise. In addition, it is both the most widely used and the most widespread form of energy in the world. Consequently, the utilization of photovoltaic energy within greenhouses constitutes a pivotal objective in achieving sustainable greenhouse crop production (Kadowaki et al., 2012).

A range of climatic parameters are known to characterize the microclimate of a greenhouse, with the set of these factors differing significantly from external conditions. Such factors, which may be categorized as temperature, relative humidity, carbon dioxide (CO_2) concentration and solar radiation, play a pivotal role in shaping the unique environmental conditions within a greenhouse. Each of these parameters exhibits a strong correlation with both external weather conditions and the unique characteristics of the greenhouse (Ezzaeri et al., 2018). As posited by numerous authors, the integration of photovoltaic panels into a greenhouse structure has been demonstrated to result in a decline in both interior light intensity and air temperature (Gorjian et al., 2021; Friman-Peretz et al., 2020).

It is also noteworthy to observe the presence of other conclusions. The author of the study draws attention to the fact that the temperature levels within both greenhouses are almost identical, with only slightly elevated temperatures recorded in the reference greenhouse (Trypanagnostopoulos et al., 2017).

The objective of the present study is to evaluate the impact of shading caused by photovoltaic panels on the microclimate in region of Baltic States. The present evaluation is concerned with ascertaining the extent to which the local climate of the region exerts an influence on the microclimate of the greenhouse under photovoltaic technology. To this end, the evaluation considers air temperature and relative humidity.

Research indicates that the photovoltaic module's surface temperature exhibited an average increase of 8 °C compared to the internal air temperature of the greenhouse. Additionally, the difference between the module temperature and the ambient temperature was recorded as 14 °C. It is noteworthy that the maximum and minimum temperatures of the photovoltaics recorded were 48.3 °C and 23 °C, respectively, while for the greenhouse operated under natural ventilation, the recorded maximum and minimum temperatures were 38 °C and 23.3 °C, correspondingly. The findings demonstrated the efficacy of integrating photovoltaic technology in the external structure of the greenhouse in mitigating the issue of overheating in the summer months (Hassanien et al., 2018). Consequently, it can be deduced that there are numerous options for the placement of solar panels on greenhouse roofs. The results indicate that there are significant temperature fluctuations in other regions; however, it should be noted that these fluctuations may vary from region to region.

Shading greenhouses have been found to be an efficacious method of achieving an optimum environment for crop growth and enhancement of crop productivity and quality in regions characterized by high temperatures and solar irradiance. The implementation of shading results in a significant reduction in air temperature within the greenhouse, typically by 5–10 °C compared to the ambient outdoor temperature. Concurrently, it leads to an enhancement in relative humidity by approximately 15–20%. As a consequence of the aforementioned, it is evident that the implementation of shading in a greenhouse results in a significant reduction in solar radiation when compared with solar radiation in a greenhouse without shading. Indeed, the reduction in solar radiation is reported to be between 30–50% (Ahemd et al., 2016).

The studies have revealed significant variations in relative humidity, which were predominantly detected at midday. The range of day relative humidity differences between the photovoltaic and control sections was found to be between 2–9%. Furthermore, relative humidity levels in both the photovoltaic shaded and control sections were found to be higher than the ambient relative humidity levels. The elevated relative humidity observed in the control section was attributed to the elevated irradiance levels, which subsequently led to increased transpiration within that particular section (Waller et al., 2021).

The application of selective filtration of light has also been demonstrated to be an effective strategy for the regulation of temperature within a greenhouse setting. The predominant heating component of light is infrared. The greenhouse can be rendered more insulated from external temperature fluctuations by reflecting the aforementioned light component. The optimal temperature range for the majority of greenhouse vegetable plants is between 20–25 °C during the day and 14–18 °C at night. In climates where temperatures are lower than 4 °C, particularly during winter, the use of heating systems becomes imperative to elevate the greenhouse's internal temperature (Ahemd et al., 2016).

Materials and Methods

The experiments were carried out within two adjacent greenhouses. These greenhouses were located at the experimental site of the Institute of Agricultural Resources and Economics in Priekuli (57.3137778 N; 25.338472222222222 E). The greenhouse was divided into two sections. Each greenhouse compartment occupies a surface area of 4 m^2, with a maximum height of 2.2 m, and wall heights of 1.5 m. The construction of both greenhouses comprises a galvanized steel profile frame, with a 4 mm thick cellular polycarbonate cover. Each greenhouse is equipped with doors at the ends, accompanied by automatically controlled window openings according to the indoor temperature.

One of the two greenhouses has been equipped with solar panels on its roof, thus ensuring complete coverage of the roof area. The configuration of these photovoltaic panels was oriented in an east-west direction, while the second greenhouse was designated as a control. The experiment was conducted using four 1765 mm long and 1043 mm wide photovoltaic panels – Figure 1, with the relevant parameters documented in Table 1.

Figure 1
Photovoltaic covered greenhouse

An investigation into the climatic parameters of the greenhouse was conducted during the fall season. However, the current research has been conducted over a single measurement period, specifically from 8 September 8.17 a.m. to 12 September 9.17 p.m. in 2024. The primary variables, including temperature and humidity, were measured and recorded on a data logger at hourly intervals, fixed at a height of 1.5 meter to the side wall. The Testo 174H data logger was utilized in conjunction with a temperature measurement range of -20 to +70 °C, with an accuracy of ±0.5 °C (-20 to +70 °C), and a humidity measurement range of 0 to 100% RH, with an accuracy of ±3% RH (2 to 98% RH).

Table 1
Characteristics of the photovoltaic panels

Name	*B60/6–370W$_p$*
Peak power (P_{max})	370 W
Open Circuit Voltage (V_{oc})	42.2 V
Short circuit Current (I_{cc})	11.25 A
Voltage	36.9 V
Current (I_{mp})	10.03 A
Solar cell	Bifacial M6, 9BB
Dimensions	1765×1043×5 mm
Weight	22 kg

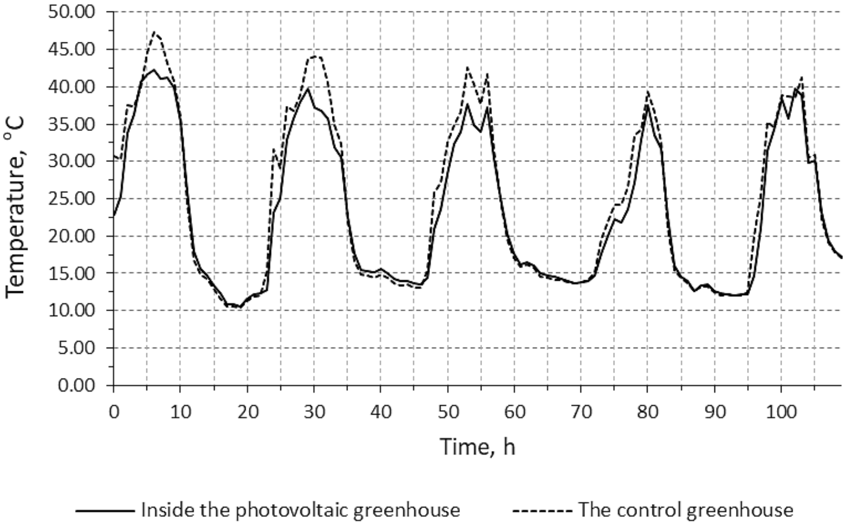
Furthermore, the distribution of internal climatic parameters in both greenhouses was measured concurrently at a designated hour, thereby ensuring the acquisition of data over a specified period, encompassing external conditions such as clouds that may have influenced the climate in both greenhouses concurrently.

Measurements of air temperature and relative humidity were taken at the equivalent point in both the photovoltaic greenhouse and the control greenhouse.

Results and Discussion

As illustrated in Figure 2, the air temperature fluctuations inside both greenhouses are presented in the form of a time graph. The data were collected over a period of five days, commencing on the 8th and concluding on the 12th of September 2024. The results indicate that the temperature fluctuations were particularly pronounced during the day, with a decline observed during nocturnal periods. The observed difference in maximum temperatures between the two greenhouses can be attributed to the combined effects of the greenhouse effect and the thermal properties of the cover.

Figure 2
Evolution of air temperature



In fact, the lowest temperature recorded in the photovoltaic greenhouse was between 10.6 °C and 13.7 °C, while the highest temperature varied between 37.5 °C and 42.2 °C. In the control greenhouse, minimum temperatures ranged from 10.4 °C to 13.7 °C, with maximum temperatures varying from 39.3 °C to 47.3 °C. The maximum observed difference in temperature between the two greenhouses was 8.5 °C.

The data gathered from the measurements indicate that during daylight hours, the air temperature within the greenhouse equipped with solar panels is lower compared to the control greenhouse. Conversely, at night, the trend is reverse, with incline in temperature observed within the solar paneled greenhouse. In the control greenhouse, a slight decline in temperature is observed. The disparity in temperature between the two greenhouses is minimal. The maximum disparity in temperature is observed to occur precisely during the day, around noon.

The varying degrees of shading, ranging from 0% to 78%, exhibited by the photovoltaic panels, along with the measured temperature range within the interior of the structure during the period of peak temperature, and on days characterized by clear skies, have been determined to fall within the optimal ranges for the cultivation of major vegetable species and this observation may be attributed to the configuration of the photovoltaic panels and their respective tilt angles (Marucci & Cappuccini, 2016). It has been demonstrated that shading has a beneficial effect on the microclimate of greenhouses. Indeed, it has been shown to enhance the cooling effect and reduce the energy required for cooling by up to 20%.

Furthermore, it has been demonstrated that shading can reduce irrigation by up to 25% (Ahemd et al., 2016).

The indoor air temperatures measured in the photovoltaic greenhouse were found to be within an acceptable range during nocturnal periods, however, during daylight hours, the temperatures were found to be elevated. In order to address this issue, it is recommended that the aperture on the side of the structure should be increased, with a view to maximizing the natural ventilation rate. The internal air temperature in the photovoltaic greenhouse was found to be lower than that of the control greenhouse during the measurement period, suggesting that the photovoltaic panels placed on the roof of the greenhouse act as shading screens (Ezzaeri et al., 2018).

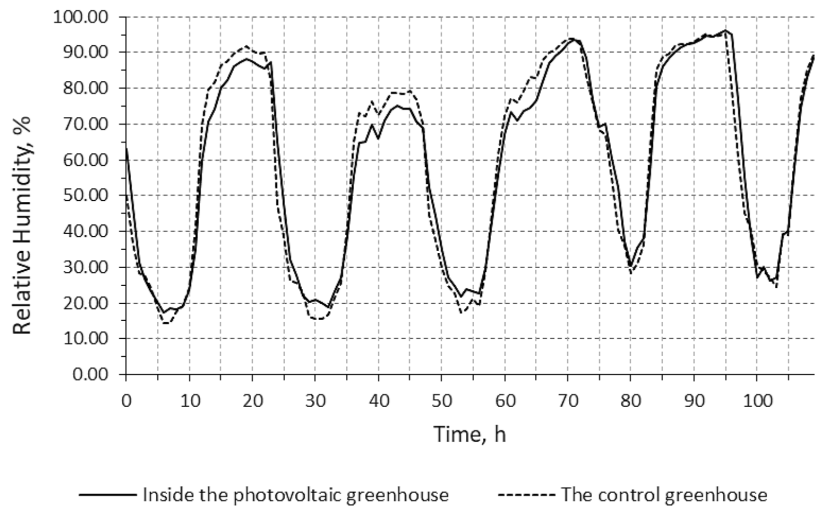
The temperature within the two greenhouses exhibited a near sinusoidal trajectory. During the summer months, the disparity in air temperature between the shaded and unshaded greenhouses was more pronounced. The unshaded greenhouse recorded a 8% increase in temperature compared to the shaded greenhouse (Ezzaeri et al., 2020).

In the context of reduced temperature levels, the energy output of photovoltaic panels is advantageous with respect to air temperature management within the greenhouse environment. This is due to by combining these panels with a charging station at night or during colder period electricity utilized for the purposes of heating the structure, thereby ensuring thermal comfort.

However, it is important to acknowledge that temperature must also be considered when assessing the impact on solar panels, since temperature is a crucial factor affecting photovoltaic cell and panel performance, along with irradiance (Cotfas et al., 2018), but the present article is not concerned with a more detailed discussion of this issue.

As illustrated in Figure 3, the hourly variations in air relative humidity within the photovoltaic and control greenhouses were monitored over the period from 8 to 12 September 2024.

Figure 3
Evolution of Relative humidity



As demonstrated in Figure 3, the variation in air relative humidity exhibits a quasi-periodic pattern, analogous to the observed quasiperiodic variation in temperature. The increase in relative humidity is indicative of a decrease in air temperature. Furthermore, the study observed that during daytime hours, relative humidity decreased to its minimum levels, while at nighttime, it increased to almost maximum levels (100% in external environments).

The values of the relative humidity recorded within the photovoltaic greenhouse ranged from 17.5% to 93.6%, while within the control greenhouse, these values ranged from 14.3% to 93.9%. The maximum discrepancy observed in the air relative humidity between the two greenhouses was 17.6%.

In addition, a comparison of the air humidity data reveals that the air humidity remains marginally lower at night in the greenhouse covered with solar panels. Conversely, during the day, the air humidity is observed to be higher in the greenhouse covered with solar panels than in the control greenhouse. The most significant disparities in measurements are evident precisely at night.

As demonstrated in other studies, the findings indicate that the range of relative humidity within the photovoltaic greenhouse, measuring from 60% to 90%, is conducive to a broad spectrum of crop growth (Marucci & Cappuccini, 2016) and research findings indicated a lower mean daily relative humidity in the control zone when compared with the zone equipped with the photovoltaic panels. This discrepancy can be attributed to the characteristics of the photovoltaic panels utilized in the study (Ureña-Sánchez et al., 2012). Lower relative humidity is unsuitable for cultivation resulting in the closure of the stomata and restricts plant environment gas exchanges thus immediately impacting photosynthesis as well as many physiological processes. Moreover, a too moist air fosters the development of fungal diseases and poor pollination of flowers. The excess or lack of moisture will strongly influence the crop productivity (Ezzaeri et al., 2018).

Conclusions

1. Although the effect caused by photovoltaics was not significant, a comparison of our findings with those from other studies clearly indicates that photovoltaics can help ameliorate the greenhouse microclimate, including in the Nordic countries of the Baltic States.
2. It has been established that this material has the capacity to serve as a constructive element, whilst simultaneously functioning as an energy source. Beyond this, the positive impact extends to the microclimate, whilst concurrently engendering a sustainable environment.
3. Future studies should concentrate on the following aspects: the amount of energy produced, the impact of solar radiation, and the microclimate within the greenhouse during plant growth. Furthermore, there is a need for further research on microclimate in different seasons. One of the objectives of this research is to determine whether integrating a photovoltaic cell can improve yields.

References

Ahemd, H. A., Al-Faraj, A. A., & Abdel-Ghany, A. M. (2016). Shading greenhouses to improve the microclimate, energy and water saving in hot regions: A review. *Scientia Horticulturae*, 201, 36–45. https://doi.org/10.1016/J.SCIENTA.2016.01.030

Cotfas, D. T., Cotfas, A., & Machidon, O. M. (2018). Study of Temperature Coefficients for Parameters of Photovoltaic Cells. *International Journal of Photoenergy*, *2018*(1). https://doi.org/10.1155/2018/5945602

Ezzaeri, K., Fatnassi, H., Bouharroud, R., Gourdo, L., Bazgaou, A., Wifaya, A., …, & Bouirden, L. (2018). The effect of photovoltaic panels on the microclimate and on the tomato production under photovoltaic canarian greenhouses. *Solar Energy*, 173, 1126–1134. https://doi.org/10.1016/J.SOLENER.2018.08.043

Ezzaeri, K., Fatnassi, H., Wifaya, A., Bazgaou, A., Aharoune, A., Poncet, C., …, & Bouirden, L. (2020). Performance of photovoltaic canarian greenhouse: A comparison study between summer and winter seasons. *Solar Energy*, 198, 275–282. https://doi.org/10.1016/J.SOLENER.2020.01.057

Fernández, E. F., Villar-Fernández, A., Montes-Romero, J., Ruiz-Torres, L., Rodrigo, P. M., Manzaneda, A. J., & Almonacid, F. (2022). Global energy assessment of the potential of photovoltaics for greenhouse farming. *Applied Energy*, *309*, Article 118474. https://doi.org/10.1016/J.APENERGY.2021.118474

Friman-Peretz, M., Ozer, S., Geoola, F., Magadley, E., Yehia, I., Levi, A., …, & Teitel, M. (2020). Microclimate and crop performance in a tunnel greenhouse shaded by organic photovoltaic modules – Comparison with conventional shaded and unshaded tunnels. *Biosystems Engineering*, 197, 12–31. https://doi.org/10.1016/J.BIOSYSTEMSENG.2020.06.007

Gorjian, S., Calise, F., Kant, K., Ahamed, M. S., Copertaro, B., Najafi, G., …, & Shamshiri, R. R. (2021). A review on opportunities for implementation of solar energy technologies in agricultural greenhouses. *Journal of Cleaner Production*, 285, Article 124807. https://doi.org/10.1016/J.JCLEPRO.2020.124807

Hassanien, R. H. E., Li, M., & Yin, F. (2018). The integration of semi-transparent photovoltaics on greenhouse roof for energy and plant production. *Renewable Energy*, 121, 377–388. https://doi.org/10.1016/J.RENENE.2018.01.044

Kadowaki, M., Yano, A., Ishizu, F., Tanaka, T., & Noda, S. (2012). Effects of greenhouse photovoltaic array shading on Welsh onion growth. *Biosystems Engineering*, *111*(3), 290–297. https://doi.org/10.1016/J.BIOSYSTEMSENG.2011.12.006

Lu, L., Ya'acob, M. E., Anuar, M. S., Chen, G., Othman, M. H., Noor Iskandar, A., & Roslan, N. (2020). Thermal analysis of a portable DSSC mini greenhouse for botanical drugs cultivation. *Energy Reports*, 6, 238–253. https://doi.org/10.1016/J.EGYR.2019.12.025

Marucci, A. & Cappuccini, A. (2016). Dynamic photovoltaic greenhouse: Energy efficiency in clear sky conditions. *Applied Energy*, 170, 362–376. https://doi.org/10.1016/J.APENERGY.2016.02.138

Trypanagnostopoulos, G., Kavga, A., Souliotis, & Tripanagnostopoulos, Y. (2017). Greenhouse performance results for roof installed photovoltaics. *Renewable Energy*, 111, 724–731. https://doi.org/10.1016/J.RENENE.2017.04.066

Ureña-Sánchez, R., Callejón-Ferre, Á. J., Pérez-Alonso, J., & Carreño-Ortega, Á. (2012). Greenhouse tomato production with electricity generation by roof-mounted flexible solar panels. *Scientia Agricola*, *69*(4), 233–239. https://doi.org/10.1590/S0103-90162012000400001

Waller, R., Kacira, M., Magadley, E., Teitel, M., & Yehia, I. (2021). Semi-Transparent Organic Photovoltaics Applied as Greenhouse Shade for Spring and Summer Tomato Production in Arid Climate. *Agronomy 2021*, *11*(6), 1152. https://doi.org/10.3390/AGRONOMY11061152

Zhao, Y., Zhu, Y., Cheng, H. W., Zheng, R., Meng, D., & Yang, Y. (2021). A review on semitransparent solar cells for agricultural application. *Materials Today Energy*, 22, Article 100852. https://doi.org/10.1016/j.mtener.2021.100852