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EXPERIMENTAL PERFORMANCE INVESTIGATION OF VERTICAL BIFACIAL SOLAR THERMAL FLAT-PLATE COLLECTORS UNDER QUASI-DYNAMIC TEST CONDITIONS

Summary

Solar District Heating is key for climate-neutral district heating, but land scarcity in urban areas hinders expansion. Vertical Agri-Solar Thermal systems with bifacial insulating glass flat-plate collectors (IGFPCs) and their inherent bifaciality, allow enhanced row spacing and therefore mitigate land use conflicts by enabling dual land use for farming and solar heat generation. To date, experimental analyses on vertical bifacial IGFPC performance have not been conducted. This study presents first-of-its-kind outdoor test results of two vertical bifacial prototypes (3.88 m² each), evaluated using the quasi-dynamic method (DIN EN ISO 9806:2018-04) with bifacial irradiance modeling (Perez anisotropic diffuse, albedo/shading). Results show peak thermal power up to 704 W/m², which is comparable to monofacial IGFPCs, with asymmetric east-west performance due to different glazing, convection effects and ambient influences. Findings enable physical model validation and performance parameter identification. Further they open discussions on bifacial test methodologies in collector testing.

Keywords: bifacial solar thermal collector, Agri-Solar Thermal, insulating glass collector, quasi-dynamic test, ISO 9806, experimental performance, dual land use, solar energy in agriculture

Field of application for the findings: Agri-Solar Thermal Systems / Dual Land Use for Solar District Heating

Addressed audience: Researchers, Engineers, Project Developers

1. Introduction

The decarbonisation of heat supply plays a major role in the energy transition. Solar District Heating (SDH) is a robust and affordable key technology for decarbonising district heating and relieving pressure on electrification efforts. However, large-scale solar thermal plants face land use conflicts in urban areas, making acceptance by citizens and municipalities hard to reach (Berberich and Mangold, 2018). Against this background, Agri-Solar Thermal (Agri-ST) systems enable dual land use for heat generation and farming. Specifically vertical bifacial systems promise high land use efficiency at similar annual solar yields compared to conventional ground-mounted systems (Summ et al., 2023). However, a technological requirement for these vertical systems are bifacial collectors that absorb solar radiation from both east and west. For this application bifacial Insulating Glass Flat-Plate Collectors are of specific interest due to their double-glass design, a highly selective absorber coating on both sides, and the hermetically sealed argon insulation. Although studies performed by Summ et al. (2023a) predict similar yields of bifacial collectors compared to south-facing plants, they only rely on analytical yield estimates. Experimental investigations on the thermal performance of IGFPCs merely focus on monofacial south-orientated applications (Summ et al., 2025), hence performance data under bifacial operating conditions has not been available. The objective of this paper is therefore to provide first-of-its-kind research results on the thermal performance of bifacial IGFPCs. To this end, two collector prototypes were tested in a long-term outdoor setup following quasi-dynamic test principles of DIN EN ISO 9806:2018-04 (DIN, 2018). The results were analysed following the standard and compared with available performance data of monofacial IGFPCs.

2. Methodology

Two bifacial IGFPC prototypes, each with a single-side aperture area of 3.88 m², were tested vertically in east-west orientation in a lab setup (see Figure 1). Both feature a highly selective coated aluminium roll-bond absorber between two glass panes, enabling the use of front- and back-side irradiation. The basic design is described in Summ et al. (2023b). Key differences of the prototypes are in glazing and hydraulic connections:

- **Collector 1** (C1; tested 22.05.2024 – 26.06.2024): Hydraulic connectors on the east side; east side: 4 mm float glass; west side: 6 mm low-iron solar glass (with anti-reflective coating).
- **Collector 2** (C2; tested 10.07.2024 – 05.09.2024): Hydraulic connectors through the sealing; both sides: 4 mm float glass

Sensors measured inlet/outlet temperatures, mass flow rate, global horizontal irradiance (GHI), wind speed, and ambient temperature.

The test is in accordance with the quasi-dynamic test (QDT) principles of DIN EN ISO 9806:2018-04 for solar thermal collectors. QDT requires four inlet temperatures equally distributed over the working range (20 °C, 30 °C, 40 °C, 60 °C, 80 °C) and variable irradiation conditions to capture transient effects. Stationary conditions were maintained only for mass flow rate (0.02 kg/s/m²) and inlet temperature. Various test sequences were run on single days to ensure sufficient variation in incidence angles and irradiance. Tests were conducted outdoors under ambient conditions, with adaptations for bifacial evaluation.

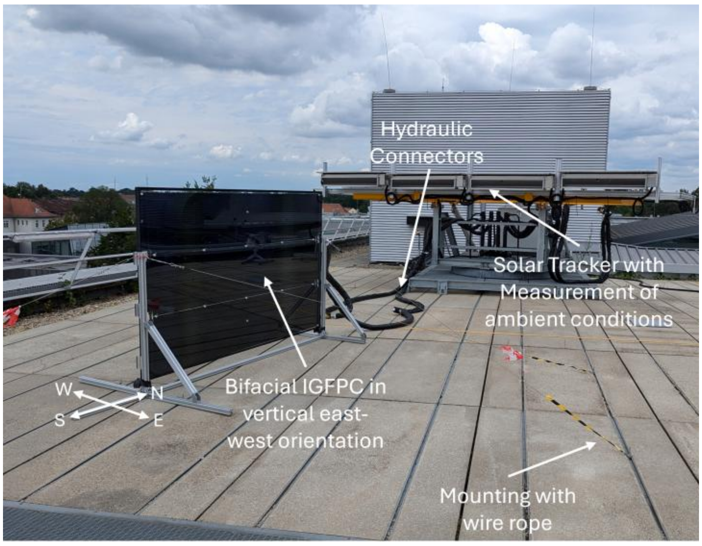

Fig. 1: Bifacial solar collector in an outdoor laboratory test-setup in Germany; Latitude: 48.76° Longitude: 11.43°

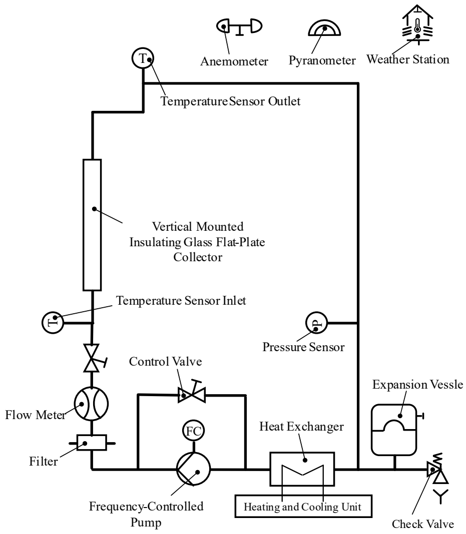

Fig. 2: Hydraulic Scheme of the test rack

For the data analysis 5 s measurement-samples were linearly interpolated to 5 min intervals. Direct normal and diffuse irradiance were calculated from measured GHI following the approach of Orgill & Hollands (Duffie and Beckman, 2013). Irradiance quality checks for physical plausibility were applied according to Long and Shi (2008) to detect physically impossible values and temporal inconsistencies. The bifacial irradiance calculation was adapted from Khan et al. (2017) and included the modelling of ground shading and albedo effects. The irradiance decomposition on the tilted surface was done using the Perez-Model (Duffie and Beckman, 2013). Following that, the data points were classified into day types per definition of DIN EN ISO 9806:2018-04. It shall be noted that bifacial modelling exceeds the standard ISO approach, therefore several adaptions had to be made.

3. Results

A specific yield profile of C2 over the course of the day of 11th of August 2024 is shown in Figure 3. The thermal power output follows a typical yield curve, which is already known from vertical bifacial PV installations, reaching a first peak at around 09:15 with 555 W/m² (normalized to single-side aperture area). At solar noon, direct irradiance on the collector plane is decreasing to nearly zero, thus the thermal power reaches its lowest value at 155 W/m². A second peak is reached at 17:30 with a peak thermal output of 648 W/m². Hence, it is evident that the thermal power output has increased by 16.7 % in comparison with the morning measurements.

Figure 4 presents the absolute thermal power output of the vertically installed bifacial IGFPC (C1) as a function of the collector temperature difference against the ambient temperature, compared to the characteristic performance curve of a monofacial IGFPC with 90% argon filling under standard rating conditions tested on a tracker (Summ et al., 2023b). Data points are colour-coded according to exposed side (east: blue, n=65.6 %; west: green, n=34.4 %). Prototype C1 achieves a maximum thermal power of 704 W/m² (2.75 kW_{th} total) at ϑ = 22.5 K, predominantly in the afternoon due to favourable west-side irradiation. The average afternoon output exceeds morning values (average: 1.57 kW_{th} vs. 1.21 kW_{th}), partly attributable to the anti-reflective solar glazing on the west side versus unglazed float glass on the east side. Thermal power declines sharply above $\vartheta > 50$ K, linked to a progressive absorber leakage. Peak power variations up to 500 W_{th} between east and west highlight asymmetric bifacial performance under varying incidence angles.

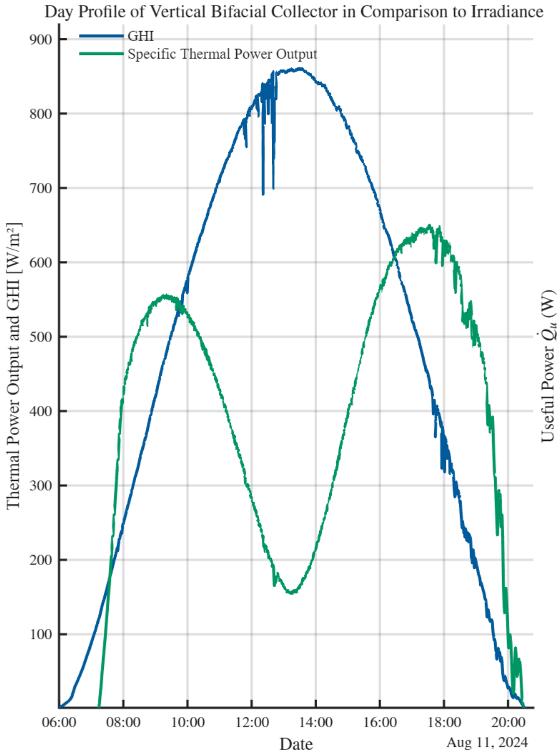

Fig. 3: GHI and Specific Thermal Power Output of prototype C2 on the 11th of August 2024

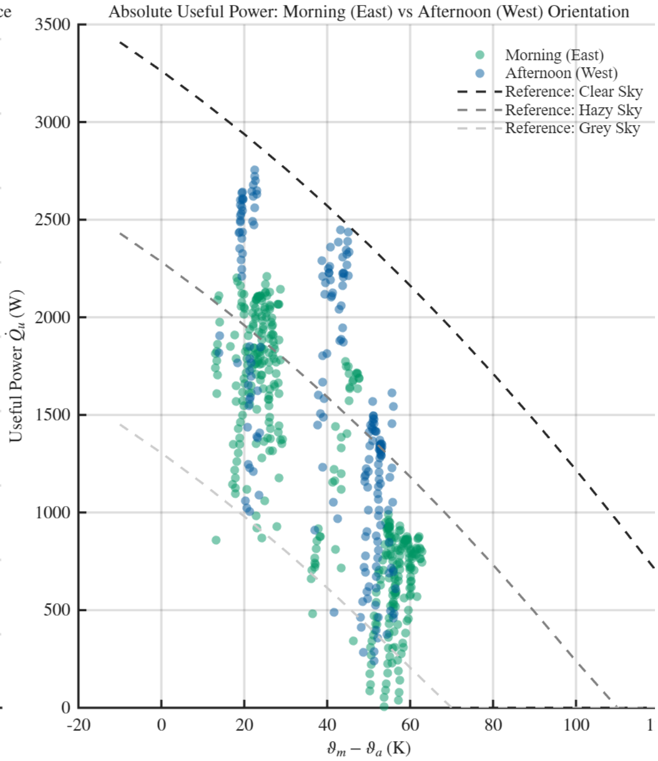

Fig 4: Characteristic thermal power of prototype C1 in comparison to a monofacial IGFPC

4. Conclusion

The present research has analysed the results of the first dynamic laboratory test of two different bifacial IGFPCs in a vertical east-west orientation. Tests were performed over a multitude of weeks and followed the procedure of DIN EN ISO 9806:2018-04 as far as applicable and with some adaptations. The investigation showed that the vertical bifacial IGFPC prototypes perform in a similar range compared to monofacial IGFPC under ideal test conditions. Peak power output reaches up to 704 W/m². The investigation also shows that morning and afternoon peaks differ. The reasons are supposed to be in different convective behaviour due to the vertical mounting position, improved clarity of afternoon atmosphere or an asymmetric ambient surface albedo distribution and require further investigation. Future research plans to validate measured thermal behaviour with a physical model and will derive collector performance parameters to enable system level simulation of vertical Agri-ST systems.

5. References

Berberich, M., Mangold, D., 2018. Solar District Heating in Europe: Supplying Renewable Zero-Emission Heat, in: Proceedings of SWC2017/SHC2017. International Solar Energy Society, Freiburg, Germany, pp. 1–10.

DIN, 2018. Solarenergie - Thermische Sonnenkollektoren - Prüfverfahren. Beuth Verlag GmbH, Berlin 27.160, 107 pp.

Duffie, J.A., Beckman, W.A., 2013. Solar engineering of thermal processes, 4th ed. John Wiley & Sons, Hoboken, New Jersey.

Khan, M.R., Hanna, A., Sun, X., Alam, M.A., 2017. Vertical bifacial solar farms: Physics, design, and global optimization. Applied Energy 206, 240–248.

Long, C.N., Shi, Y., 2008. An Automated Quality Assessment and Control Algorithm for Surface Radiation Measurements. TOASCJ 2 (1), 23–37.

Summ, T., Ehrenwirth, M., Trinkl, C., Zörner, W., 2023a. Agri Solar Thermal Systems: A Brief Study on the Energetic Potential of Bifacial Solar Thermal Systems, in: EuroSun2022. 25-29 September 2022, Kassel, Germany : proceedings : ISES and IEA SHC International Conference on Solar Energy for Buildings and Industry. International Solar Energy Society, Freiburg, Germany, pp. 1–8.

Summ, T., Ehrenwirth, M., Trinkl, C., Zörner, W., Pischow, K., Greenough, R., Oyinlola, M., 2023b. Effect of argon concentration on thermal efficiency of gas-filled insulating glass flat-plate collectors. Applied Thermal Engineering 230.

Summ, T., Oyinlola, M., Khattak, S., Ehrenwirth, M., Trinkl, C., Zörner, W., 2025. Towards maximum cost-effectiveness: multi-objective design optimisation of insulating glass flat-plate collectors. Applied Thermal Engineering 258, 124594.