FIELD-MONITORED LIFE CYCLE AND TECHNO-ECONOMIC ASSESSMENT OF THERMOSYPHON AND PV2HEAT DOMESTIC HOT WATER SYSTEMS IN NAMIBIA: TOWARDS A FULL-YEAR SIDE-BY-SIDE COMPARISON

Summary

Domestic solar hot water systems are a relevant option for decarbonizing heat supply in Namibia and other Sunbelt regions. This study compares three small-scale systems installed side by side at the NUST Science and Technology Park in Namibia. The investigated systems are an indirect thermosyphon system with flat-plate collector, an indirect thermosyphon system with evacuated heat pipe collector, and a PV2Heat system. The work combines field monitoring, system inventory, life cycle assessment, and techno-economic evaluation.

Its main innovative aspect is the harmonized comparison of solar thermal and PV-based hot water systems within one common experimental platform and one consistent methodological framework. At the time of abstract submission, the monitoring campaign is still ongoing, but the full 12-month dataset will be available for the final paper.

Keywords: Domestic hot water, thermosyphon, PV2Heat, life cycle assessment, techno-economic assessment, field monitoring, Namibia, Sunbelt regions

Field of application for the findings: The findings support the selection and assessment of small-scale solar domestic hot water systems for households and small buildings in Namibia and comparable high-irradiation regions.

Addressed audience: The contribution addresses researchers, technology developers, energy planners, and decision-makers working on sustainable solar hot water solutions and their environmental and economic evaluation.

1. Introduction

Domestic hot water is a promising field for reducing electricity demand and greenhouse gas emissions in high-irradiation regions. In Namibia, where solar resources are excellent and electric resistance water heating is still common, solar-based hot water systems can contribute significantly to a more sustainable and cost-efficient energy supply (Republic of Namibia, 2021; Weiss and Spörk-Dür, 2023). Two relevant technology options are thermosyphon solar thermal systems and photovoltaic-driven electric water heating systems (PV2Heat).

Despite their practical relevance, direct comparisons under identical boundary conditions remain limited, especially for household-scale applications in Sub-Saharan Africa. Many published studies rely on simulations, manufacturer data, or datasets generated under different climatic and operational conditions, which limits comparability (Buckley et al., 2019; Kicker et al., 2017, 2018; Shimhanda et al., 2018).

This study addresses this gap through a side-by-side assessment of three small-scale domestic hot water systems installed at the NUST Science and Technology Park in Namibia: an indirect thermosyphon system with flat-plate collector, an indirect thermosyphon system with evacuated heat pipe collector, and a PV2Heat system. All systems are based on a 200 L storage volume and comparable installed capacity. The aim is to establish a harmonized framework for comparing environmental and techno-economic performance under identical real-world conditions.

2. Experimental setup and assessment framework

The three systems are installed in a common experimental setup based on a 12 m shipping container. The storage tank, monitoring system, and control equipment of the PV2Heat system are located inside the container, while the collector and PV components are mounted externally. This setup allows parallel operation of all systems at the same site and under the same ambient conditions. Figure 1 illustrates the layout of the container-based experimental setup located at the NUST Science and Technology Park in Namibia.

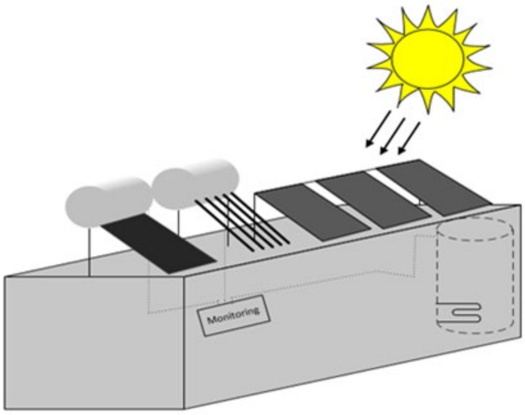

Fig. 1: Experimental setup of the side-by-side comparison of thermosyphon and PV hot water systems

The assessment combines four elements: field monitoring, detailed system inventory, life cycle assessment (LCA), and techno-economic evaluation. The methodological strength of the study lies in the direct side-by-side comparison of solar thermal and PV-based hot water systems within one common experimental platform and one consistent assessment framework. This substantially improves comparability and reduces uncertainties caused by differing climate data, operating assumptions, or system boundaries, which have limited previous comparative studies (Buckley et al., 2019; Shimhanda et al., 2018).

3. Innovative aspects of the work

The main innovative contribution lies in the comparative assessment architecture rather than in the individual technologies. Two thermosyphon concepts and one PV2Heat concept are evaluated at one location, under identical boundary conditions, and within one harmonized methodological framework. This provides a more robust basis for technology comparison than separated case studies reported in earlier work (Buckley et al., 2019; Kicker et al., 2018; Shimhanda et al., 2018).

A second innovative aspect is the integration of field monitoring with LCA and techno-economic assessment. This allows environmental and economic indicators to be interpreted together, which is highly relevant for real-world implementation. A third important aspect is the application-oriented focus on Namibia and comparable Sunbelt regions, where reliable, affordable, and sustainable hot water systems are needed (Republic of Namibia, 2021; Weiss and Spörk-Dür, 2023).

4. Current status and results available at the time of submission

At the time of conference submission, the monitoring campaign is still ongoing. Therefore, this contribution does not yet report final annual performance and life cycle results. However, several relevant intermediate results are already available.

The experimental platform has been successfully established and commissioned. The three systems are installed in a common test environment and prepared for harmonized monitoring. In parallel, the foreground inventory data required for the environmental and economic assessment have been compiled on the basis of detailed planning and on-site data collection. The LCA structure, system boundaries, and comparison logic have thus already been defined on a consistent basis.

By the time of full paper submission, the complete 12-month dataset will be available. The final paper will therefore report annual system performance, seasonal behavior, comparative environmental indicators, and techno-economic results for all three systems. This ensures that the final assessment will be based on a full-year empirical dataset rather than on extrapolated assumptions alone.

5. Relevance for the field of application

The study is directly relevant to small-scale solar domestic hot water supply in Namibia and related high-irradiation regions. This application is particularly important because domestic hot water represents a recurring thermal demand that can be shifted from conventional electric heating to renewable systems with comparatively low technical complexity.

The comparison between thermosyphon and PV2Heat systems is valuable because both approaches offer distinct advantages. Thermosyphon systems are often associated with simplicity and direct solar thermal conversion, while PV2Heat systems may offer benefits in modularity and integration into broader electrification strategies. The results of this study are intended to support technology selection for households, building owners, planners, and policy stakeholders.

6. Conclusions

This study presents a field-based framework for comparing thermosyphon and PV2Heat domestic hot water systems in Namibia by combining field monitoring, LCA, and techno-economic assessment. Its key strength is the side-by-side evaluation of three comparable systems under identical site conditions and within one harmonized methodology.

At the current stage, the main results are the successful implementation of the experimental platform, the preparation of the monitoring framework, and the completion of the core inventory basis for environmental and economic assessment. The full annual dataset will be available for the final paper and will provide a robust basis for comparing the environmental and techno-economic performance of the investigated solar hot water concepts.

7. Selected References

Buckley, A. I., Kritzinger, K., Moschik, R., Mamphweli, S., and Spörk-Dür, M. (2019). Comparison of photovoltaic- and solar thermal hot water systems in the South African context. In Proceedings of the ISES Solar World Congress 2019.

Kicker, H., Lang, R., and Wallner, G. (2017). Sustainability assessment of solar thermal collector systems. In Proceedings of the ISES Solar World Conference 2017 and IEA SHC Conference 2017.

Kicker, H., Wallner, G., and Lang, R. (2018). Sustainability assessment of most relevant solar thermal heat systems. In Proceedings of the 12th EuroSun Conference.

Republic of Namibia (2021). Namibia's NDC Update. UNFCCC.

Shimhanda, S., Ileka, H., and Shidhika, F. (2018). A comparative study of solar water heater and photovoltaic water heater in Windhoek. ISEC.

Weiss, W., and Spörk-Dür, M. (2023). Solar Heat Worldwide. Edition 2023. IEA Solar Heating & Cooling Programme.