MONITORING-BASED PERFORMANCE ASSESSMENT AND IMPACT ASSESSMENT OF SOLAR THERMAL AND PVT SYSTEMS IN SOUTHERN AFRICA

Summary

This paper presents monitored performance results from selected SOLTRAIN demonstration systems in Southern Africa and evaluates the relationship between high solar resource availability and real system performance. Annual global irradiation levels between 1,900 and 2,400 kWh/m²·a enable specific collector yields of 650–880 kWh/m²·a under monitored operating conditions. Solar fractions up to 84% for large hospital applications and up to 100% renewable fraction in hybrid PVT–heat pump configurations were achieved (PVT results based on simulations). Continuous monitoring allowed identification of hydraulic inefficiencies, parasitic losses, and stagnation events. The implementation of control adaptations, including night cooling strategies, measurably reduced stagnation occurrences and increased usable annual yield. The results demonstrate that systematic monitoring is essential for performance optimization, long-term reliability, and scalable renewable heat deployment in high-irradiation regions.

Keywords: Solar thermal monitoring, solar fraction, stagnation control, specific collector yield, solar resource assessment, PVT systems

Field of application for the findings: Sustainable Heating and Cooling Systems for Buildings; Energy Efficient Buildings: Solar and Efficient Buildings

Addressed audience: Researchers, system designers, consultants, policymakers, and development cooperation stakeholders

1. Introduction

The Southern African Development Community (SADC) region benefits from annual global solar irradiation between 1,800 and 2,400 kWh/m²·a, significantly exceeding typical Central European levels. Despite these excellent solar resource conditions, the installed solar thermal capacity remains comparatively low. This contrast between resource potential and deployment reality underscores the need for quality-assured implementation and performance verification.

The SOLTRAIN initiative has installed numerous demonstration systems across Southern Africa in residential, commercial, and healthcare applications. A subset of these systems was equipped with detailed monitoring infrastructure to assess real-world performance, quantify solar fractions, and identify optimization potential. This paper focuses on monitored systems and evaluates how data-driven analysis enhances reliability, efficiency, and stagnation management.

However, high solar resource alone does not automatically translate into high system performance. Real-world operation depends strongly on hydraulic design, control strategies, load profiles, and loss management. Therefore, systematic monitoring is required to evaluate the actual conversion efficiency between available irradiation and useful thermal output.

2. Monitoring Concept and Methodology

Monitoring systems include heat meters on collector and hot water circuits, temperature sensors at key hydraulic points, mass flow measurement, electrical meters (where applicable), and global radiation sensors.

Data logging was performed at high temporal resolution, enabling detailed analysis of daily and seasonal performance behavior.

Solar yield was determined from measured heat output, while solar fraction was calculated as the ratio between useful solar heat and total thermal demand. Emphasis was placed on identifying parasitic losses, ring main losses, control inefficiencies, and stagnation events.

Annual performance was evaluated by correlating measured global irradiation (G) with useful thermal output (Q_u), enabling assessment of effective system conversion performance under real operating conditions.

3. Selected Demonstration Systems and Monitoring Results

To illustrate the practical impact and technical potential of solar thermal deployment in Southern Africa, the following monitored demonstration systems are presented. These case studies represent different scales and applications, highlighting both the outstanding solar resource conditions of the region and the decisive role of systematic monitoring as a reference for the 903 installed systems in Africa during the SOLTRAIN project. Together, they demonstrate how high solar fractions can be achieved, how operational challenges such as stagnation can be identified and mitigated, and why monitoring is essential for ensuring long-term system performance and reliability.

3.1 Katutura Hospital, Windhoek

A hospital-scale solar thermal installation in Windhoek achieved a monitored specific collector yield of 797 kWh/m²·a under annual global irradiation levels around 2,000 kWh/m²·a, as seen in Figure 1. The resulting performance demonstrates effective utilization of available solar resources. Following monitoring-based optimization of mass flow settings and control parameters, annual solar fraction increased to 84% in 2025. The data confirms that hydraulic optimization directly improves conversion efficiency and usable solar contribution.

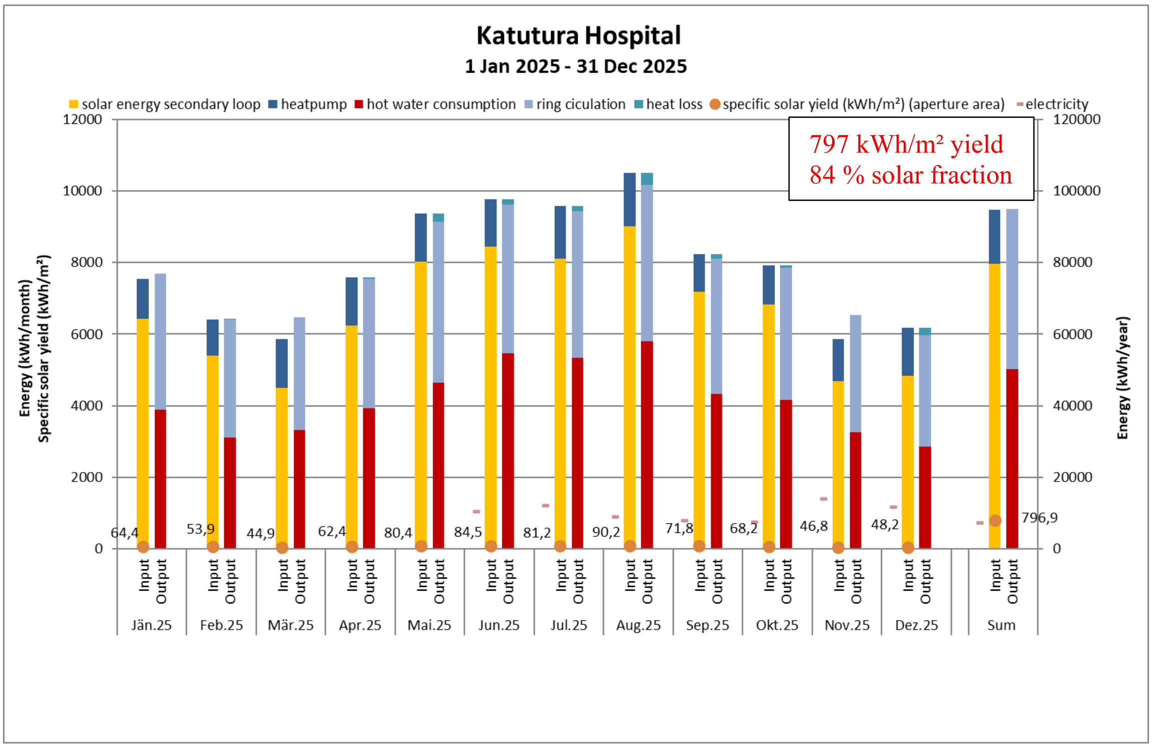

Figure 1 Measured energy balance of Katutura Hospital over a period of 12 months

3.2 Mediclinic Hospital, Cape Town (PVT + Heat Pump Integration)

The monitored hybrid PVT and heat pump system demonstrates the technical feasibility of achieving a fully renewable domestic hot water supply. Approximately 55% of annual heat demand is covered directly by solar thermal output from PVT collectors, while the remaining demand is supplied by high-efficiency heat pumps powered by solar-generated electricity. Under monitored boundary conditions, the system achieves net-zero external electricity demand for hot water preparation, illustrating the potential of sector-coupled solutions in high-irradiation regions.

3.3 University of Botswana Hostels and BDF Village

Medium-scale residential systems achieved specific yields in the range of 650-750 kWh/m²·a. Monitoring identified typical operational challenges, like periods of longer holidays, including circulation losses and temporary stagnation events. Optimization measures derived from monitoring data improved overall system stability and solar fraction performance. These applications illustrate the transferability of high-performance solar thermal solutions to multi-building contexts.

4. Stagnation Detection and Control Optimization

Monitoring data revealed collector stagnation during periods of high irradiation combined with low thermal demand. Temperature profiles clearly identified stagnation phases and peak collector temperatures. The implementation of night cooling strategies reduced storage temperature prior to high irradiation days and significantly decreased stagnation occurrences. This control adaptation increased annual usable solar yield and improved long-term system stability. The findings demonstrate that stagnation mitigation is not solely a design issue but a dynamic operational challenge that can be addressed through data-driven control strategies.

5. Discussion

Across all monitored systems, a clear relationship between solar resource availability and achievable specific collector yield was observed. However, monitoring results confirm that high irradiation alone does not guarantee high solar fraction. Hydraulic optimization, loss reduction, and intelligent control strategies are decisive factors. Compared to typical Central European installations (450–550 kWh/m²·a), the monitored Southern African systems achieve significantly higher specific yields, primarily due to superior solar resource combined with performance-oriented operation.

Furthermore, systematic monitoring enhances investment security, improves system reliability, and enables evidence-based scaling of renewable heat technologies in emerging markets.

6. Conclusion

Monitoring of solar thermal and PVT systems in Southern Africa confirms that specific yields above 750 kWh/m²·a and high solar fractions are technically achievable under favorable irradiation conditions. Data-driven optimization reduces stagnation, improves control performance, and increases usable annual yield. The results demonstrate that systematic monitoring is a prerequisite for reliable, scalable, and economically robust renewable heat deployment. In high-irradiation regions, monitored solar thermal systems can contribute substantially to grid relief and long-term decarbonization of building heat supply.