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Monitoring and Evaluation of Thermosyphon and PV Hot Water Systems Under the Same Operating Conditions in a Side-By-Side Experimental Setup

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Abstract. Renewable heating and cooling are the primary focus of the Southern African Renewable Heating and Cooling Training and Demonstration Initiative in creating capacity pertaining to this subject. This emphasis is aligned with the United Nation's 2030 Agenda, which seeks for carbon-neutrality by the year 2030. To address thermal needs on small-scale, thermosiphons systems using evacuated tube collectors, flat-plate collectors, and photovoltaic to heat systems are frequently used. For a scale-up application of these technologies, and for accelerated achievement of carbon-neutrality, a cost-effective technology must be prioritised in various areas of the world with different meteorological conditions. This study therefore intends to establish the technical performance and the cost-effectiveness of these technologies in Namibia's environment whilst replicating a small-scale house daily hot water demand.

Keywords: Solar Water Heating, Thermosyphon, Photovoltaic

1. Introduction

The demand for hot water is increasing globally, and many countries have set targets to encourage a higher fraction of their energy production to come from solar technologies. Through its Solar Thermal Roadmap, Namibia targets to have installed 1 500 000 m^2 of solar thermal collector area by the year 2030 [1]. Two technologies that are expected to play the biggest role in the solar hot water market by 2030 are solar thermal thermosyphon and solar photovoltaic (PV) derived hot water heating systems. These technologies are especially promising for the Sunbelt region (between the 20th and 40th degrees of latitude in the northern and southern hemispheres), where Namibia is located [2]. According to Namibia's Updated Nationally Determined Contributions (NDCs) to curb climate change, Namibia has a strong focus on avoiding 91 % of its greenhouse gases (GHG) emissions by 2030 [3]. By targeting mitigation in the energy sector, which is the second largest GHGs emission sector in Namibia, one of the strategies would be to separate heating from fossil fuel-based electricity. This can be done by the implementation of proven solar water heating technologies in place of the traditional boilers and electric water heaters, which are associated with CO_2 emissions.

In doing so, technological solutions should be cost-effective for end users so that the continued utilisation of these technologies is sustainable. To date, data or literature that substantively suggests which solar water heating technology is most cost-effective and suitable for given boundary conditions (e.g., hot water consumption profiles, solar irradiance levels) is scarce. There is a lack of comprehensive comparison studies of thermosyphon and PV hot water systems for household applications under real-life conditions, in particular for Namibia. A comparative study of a flat plate thermosyphon solar water heater and a photovoltaic water heater conducted by the Namibia Energy Institute (NEI) revealed that it is convenient in terms of installation and technical operation to have a photovoltaic water heater over a flat plate thermosyphon solar water heater due to its simplicity [4]. This study was however based on actual energy consumption patterns, which were distinct for the two different installations; therefore, the results do not reflect a fair comparison. Furthermore, the study did not extend to the other technology, which is commonly being utilised, the thermosiphon water heaters with evacuated tube solar water heating technology.

Another similar study conducted in South Africa demonstrate that a thermosyphon system is more cost effective [5]. Similarly, this study excluded the evacuated tube collector system, and has not emphasized on technical performance. It is against this background that NEI, through the Southern African Renewable Heating and Cooling Training and Demonstration Initiative (SOLTRAIN+) and IEA SHC Task 69 intend to undertake this study. The proposed study will provide comprehensive information while addressing the gaps in similar studies. The comparative study will also contribute to IEA SHC Task 69, where the system designs of solar hot water technologies are analysed, and market studies are performed.

2. Experimental Set-Up and Methodology

Three designs are proposed, each unit consisting of a 200 litres tank and collectors/PV modules with 1.2-1.6 kW equivalent nominal thermal power/kW$_P$. The three systems are:

System 1: Indirect thermosyphon system with a flat plate collector;

System 2: Indirect thermosyphon system with evacuated heat pipe collector; and

System 3: PV-to-Heat (PV2Heat) system.

Figure 1 illustrates the setup of the system, whereby all collectors and the PV modules with the same azimuth and tilt angles are fixed on the roof of the container, and the PV2Heat system's storage tank and the monitoring & controls are installed within the container.

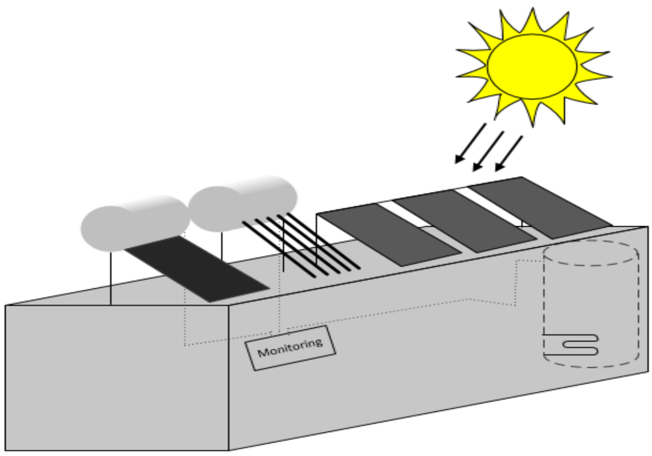

Figure 1: The side-by-side experimental set-up of various solar water heating systems.

The overall objective of this setup is to conduct a side-by-side comparison of small-scale installations for solar-derived hot water. The system will be equipped with a monitoring system that logs all the data pertaining to the performance of the systems, such as hot water temperature and hot water flow rate. Primarily, the hot water temperature profiles within the tanks of the three systems will be analysed to establish which system produces the most heat and at what cost and establish the levelised cost of thermal energy (LCOE). The three systems will be installed on a 12 m shipping container, with the monitoring system, controls, and the storage tank of the PV2Heat system installed within the container. The container will be erected at the Science and Technovation Park at NUST. Figure 2 illustrates a single line diagram of the interconnection of the three systems set up, as well as the major monitoring equipment. The three systems will be automated to operate in a controlled manner that replicates hot water consumption of a small-scale household whereby the return temperature and the mass flow rate for all three systems will be the same.

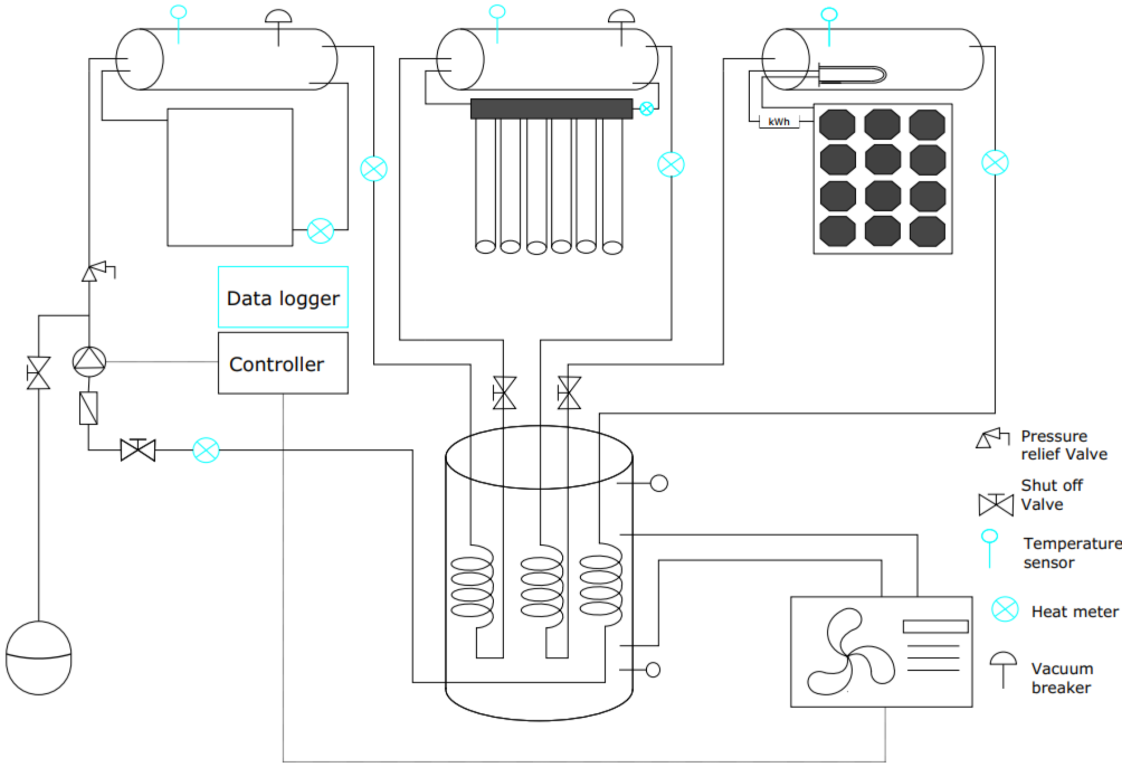

Figure 2: A schematic of the side-by-side of the solar water heater set up.

Apart from the solar water heating components, a cooling system is incorporated to instantly cool the hot water. This is implemented as a water conservation measure i.e., a closed loop on the hot line is incorporated to eliminate waste of hot water. A 12 kW heat pump with 4 kW cooling capacity will dissipate heat from a 1200 litres heat accumulator. The temperature within the heat accumulator is expected to be in a range of 40 °C - 60 °C. In the system, there is also safety devices incorporated in case the heat and pressure in the system exceeds nominal operating temperature and pressure of the systems. The ambient temperature, irradiation data and hot water temperature in the tanks will also be measured and logged.

3. Expected Outcome

The project is currently in the procurement of all components phase. It is expected that there will be no hurdle in monitoring and gathering metrological data as well as the technometrics of the system. Under the SOLTRAIN+ project, NEI has already monitored some domestic small-scale solar water heating systems hence it is a usual experience for the institute. The monitoring system should be able to inform on the ability of these systems to supply hot water for the predetermined water consumption profile that replicates the hot water demand of a small-scale household. By controlling the hot water consumption profile, the experimental setup allows a fair comparison of the three technologies, which was not present in previous work. It will further be established whether the storage tanks are able to retain the heat produced during the day. By having the cost of the components of the system, the LCOE can be established, and it can serve as an indicator of cost-effectiveness. Furthermore, it is planned to perform a detailed life cycle assessment (LCA) of the systems.

4. Conclusion

The study will contribute to NUST's Green Vision of 2030, which aspires to contribute towards a future where all energy is consumed from sustainable sources and sustained by a public that understands and values the social, economic, and environmental benefits that green energy provides to communities, nations, and beyond through an integrated green energy creative value chain. In addition, the study will provide evidence-based information to the industry regarding the best systems suitable for the Namibian climatic conditions, considering the economic, environmental, and technical performance of the systems. Similarly, the results of the study will support market confidence in these technologies.

Data availability statement

There is minimal primary data available from the study since the systems have not been physically set-up yet. Specification sheets of the main components, solar water heaters, PV modules, heat pump, hot water accumulator, and thermosyphon hot water collectors will assist in the analysis. The exact specifications will be obtained once the components are procured.

Underlying and related material

The are no underlying and related material.

Author contributions

Joseph Shigwedha: Conceptualization, Data curation, Investigation, Methodology, Project administration, Resources, Visualization, Writing – original draft. **Fenni Shidhika:** Conceptualization, Project administration, Writing – review & editing. **Helvi Ileka:** Conceptualization, Funding acquisition, Project administration, Writing – review & editing. **Daniel Tscopp:** Validation, Writing – review & editing. **Rudi Moschik:** Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Supervision, Writing – review & editing. **Penti Paulus:** Conceptualization, Data curation, Project administration, Writing – review & editing.

Competing interests

The authors declare that they have no competing interests.

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