Solar World Congress 2025

Off-Grid Solar Systems for Healthcare in Africa: Solutions for Cooling, Heating, and Clean Water with the SophiA Concept

Summary

Hospitals and healthcare facilities in rural, remote regions of Africa face various challenges in their daily operations. Power supplies are often unreliable, and clean water is lacking. Within the EU project SophiA, solar powered containerized and modular solutions for cooling (+5°C to -70°C) using natural refrigerants, cooled drinking water and deionized water for medical purpose, as well as hot water and electricity were developed. The systems were manufactured in South Africa and installed in four demo sites in Burkina Faso, Cameroon, Malawi, and Uganda. Life Cycle Assessment (LCA) analysis indicates a reduction of the environmental impact with ~50% compared to grid-based systems, supporting the viability of SophiA off-grid concept for critical healthcare services.

Keywords: sustainable cooling, natural refrigerants, ice storage, drinking and deionized water, Scheffler reflectors, photovoltaics, PVsteamCube, sterilization, institutional cooking with solar, healthcare, Africa

1. Introduction

The SophiA project aims to transform energy access in African healthcare through sustainable, container-based solutions. Many rural hospitals lack access to stable electricity and clean water, directly impacting medical service quality.

Funded by the European Horizon 2020 programme, SophiA provides sustainable cooling and heating solutions, as well as clean and safe water, to rural and remote hospitals, by using solar energy, and thus accelerating the green transition and energy access in Africa

First generation SophiA consists of two solar-powered, modular container solutions, which can be easily integrated into existing infrastructures. Using natural refrigerants, SophiA cooling container provides:

- low and ultra-low temperature storage of blood plasma and sensitive drugs [-30°C] [-70°C]

- cooling of medicines and food [+5°C]

Using PV, solar thermal and Scheffler reflectors, SophiA water container provides:

- drinking water and pure water for medical purposes

- steam and hot water.

The integration of thermal storage for cooling (ice storage) and high temperature (PVsteamCube) for cleaning, disinfection and institutional cooking provides an added value and increases the self-sufficiency in remote healthcare facilities.

Additionally, the PV MedPort, a 100% solar mobile unit is designed as a versatile mini healthcare station.

These containerized systems are designed for deployment in remote hospitals and are tested in Burkina Faso, Cameroon, Malawi, and Uganda. All systems are monitored remotely allowing anomalies detection in real-time, reduce the downtime significantly and providing insights on predictive maintenance.

Life Cycle Assessment (LCA) analysis was performed to assess the environmental impact. A comparison of the SophiA system with diesel- and grid-based alternatives across different irradiance and energy mix scenarios was made. Two impact assessment methodologies were used (Global Warming Potential "IPCC 2021 GWP 100a" and the Product Environmental Footprint 3.1).

2. Project Concept and Implementation

The SophiA systems are composed of solar photovoltaic (PV) panels, solar thermal collectors, and advanced energy storage technologies, all integrated into transportable containers. The first-generation deployment consists of two primary containerized units: a Solar Cooling Container and a Solar Water Container. The Solar Cooling Container provides medical-grade refrigeration at multiple temperature levels, including +5 °C for medicines, –30 °C for blood plasma, and –70 °C for vaccines. It also supports space cooling for surgical and intensive care units. The Solar Water Container supplies clean drinking water, hot water, and steam used for sterilization, laundry and cooking purposes.

Key technologies within the SophiA system include photovoltaic modules for electricity generation, solar thermal collectors combined with the PVSteamCube - a patented high-temperature thermal storage unit that generates steam at near-ambient pressure, and both battery and ice-based thermal storage systems to guarantee uninterrupted 24/7 operation. The system also integrates advanced water purification technologies capable of eliminating bacteria and viruses, ensuring safe, potable water. Cooling systems use environmentally safe natural refrigerants such as R-290 and CO_2, which have low global warming potential and avoid the formation of persistent PFAS compounds.

An additional innovation is the PVmedPort which doesn't require long installation process, a mobile, solar-powered health station designed for deployment in highly remote regions. It functions independently, providing power, lighting, and shelter, and can be adapted for use as a vaccination center. The entire SophiA setup is coordinated by a smart supervisory control and data acquisition (SCADA) system that monitors environmental conditions, balances energy loads, and optimizes performance as well as proving performance data.

3. Demonstration Sites and Technical Approach

Demonstration units of the SophiA system are being implemented across four African countries: Burkina Faso, Cameroon, Malawi, and Uganda. Each site follows a structured deployment process that begins with an assessment of the existing healthcare infrastructure and energy requirements. Following this, the modular container systems are installed and commissioned to ensure seamless integration with the local facilities. Performance is continuously monitored, including metrics such as energy generation, system reliability, thermal efficiency, water quality, and overall operational stability. Sensors and remote monitoring technologies, combined with training for local staff, enable effective data collection and autonomous operation. This real-time feedback loop facilitates continuous design refinement and informs future scaling and replication strategies for broader impact.

4. Innovation and Renewable Energy Applications

SophiA embodies applied innovation in the field of renewable energy systems by integrating a range of advanced technologies and implementation strategies tailored to medical infrastructure. It combines photovoltaic (PV) and solar thermal energy systems to provide reliable, off-grid power for essential healthcare functions. The project features multi-tiered thermal storage solutions, including ice storage and phase change materials (PCM), to support consistent medical-grade refrigeration. The use of natural, environmentally safe refrigerants enables deep-freezing capabilities without dependence on the electrical grid, and cooking with non-electric applications. Furthermore, the systems are designed for local manufacturing and assembly within Africa, promoting regional economic development and technical independence. SophiA also prioritizes capacity building through targeted training programs for healthcare workers and technicians, ensuring long-term operational sustainability. Collectively, these innovations position SophiA as a leading model for the application of sustainable renewable energy solutions in critical public service infrastructure.

5. Conclusion

SophiA demonstrates that renewable off-grid systems can deliver reliable energy, cooling, and water services to remote healthcare facilities. The project sets a precedent for modular, sustainable, and scalable energy infrastructures tailored to low-resource environments. Its alignment with local manufacturing, climate resilience, and real-world healthcare needs exemplifies best practices in the renewable systems application domain.

6. References

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