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SophiA: A Mobile Healthcare System for Cooling, Heating and Clean Water Supply

Summary

Reliable energy, refrigeration, hot water, sterilization, and clean drinking water are essential for healthcare delivery, yet many rural hospitals in Africa continue to face unstable electricity supply and insufficient technical infrastructure. The SophiA concept addresses this challenge through an integrated off-grid renewable energy system that combines solar photovoltaic power, solar thermal energy, electrical and thermal storage, medical refrigeration, hot water production, steam generation, and water purification in modular containerized units. The system is designed to provide medical cooling at +5 °C, freezing at -30 °C, ultra-low-temperature storage at -70 °C, and clean water and thermal services for clinical and domestic use. Demonstration activities in Burkina Faso, Cameroon, Malawi, and Uganda show that the concept is technically feasible for rural healthcare applications. Environmental assessment further indicates that the SophiA system can reduce environmental impacts by around 50% compared with conventional grid-based alternatives, while providing higher autonomy and resilience in weak-grid or no-grid areas. These results support the use of integrated off-grid solar systems as a scalable and sustainable solution for critical healthcare and medical services in remote regions.

Keywords: Off-grid solar systems, healthcare, Africa, medical refrigeration, solar thermal, photovoltaics, water purification, natural refrigerants, sustainability, life cycle assessment

Field of application for the findings: Remote and weak-grid healthcare facilities, particularly rural hospitals, health posts, vaccination centers, and pharmaceutical storage applications in Africa and similar regions. The concept is especially relevant where reliable electricity, medical cold chains, sterilization heat, and safe water supply are not consistently available.

Addressed audience: Researchers and engineers in solar energy and off-grid systems, healthcare infrastructure planners, policy makers, development agencies, technology providers, and practitioners involved in rural electrification, medical cold chains, sustainable thermal systems, and decentralized water treatment.

1. Introduction

Reliable access to electricity and clean water is a prerequisite for safe and effective healthcare, yet it remains unavailable or unstable in many rural regions of Africa. As a result, hospitals, clinics, and health posts often face major difficulties in preserving vaccines, medicines, and blood products, operating sterilization processes, maintaining hygienic conditions, and ensuring continuous service delivery. These constraints are particularly critical in remote areas, where weak infrastructure, unreliable grids, and dependence on diesel generators increase operational costs, environmental burdens, and the risk of healthcare disruption. To address this gap, the SophiA project developed an integrated off-grid renewable energy system tailored to the needs of rural healthcare facilities. The concept combines solar photovoltaic and solar thermal technologies with medical cooling, hot water generation, steam-based sterilization, and water purification in a modular container-based platform. Its objective is to provide a robust and sustainable infrastructure for essential healthcare services while reducing fossil-fuel dependence, lowering environmental impacts, and improving local autonomy. In addition, the system is designed to enhance service resilience under challenging climatic and infrastructural conditions and to support long-term operation through locally adaptable and scalable technical solutions. By linking decentralized renewable energy with critical medical functions, SophiA demonstrates a practical pathway toward resilient, low-carbon healthcare infrastructure for underserved and hard-to-reach communities in Africa.

2. System Architecture and Implementation

The SophiA system integrates solar photovoltaic modules, solar thermal collectors, battery storage, thermal storage, medical cooling technologies, and water treatment units into transportable containerized platforms for off-grid healthcare applications. The concept is implemented through two main units: the Solar Cooling Container and the Solar Water Container. The Solar Cooling Container provides medical-grade temperature control for medicines, blood plasma, and vaccines at +5 °C, -30 °C, and -70 °C, and can also support space cooling for sensitive hospital areas. The Solar Water Container supplies potable water, hot water, and steam for sterilization, laundry, and cooking. Continuous operation is ensured through a combination of electrical and thermal storage, while integrated water purification technologies provide safe drinking water through the removal of biological contaminants.

A key technological feature of the system is the integration of the PVSteamCube, a patented high-temperature thermal storage unit that enables steam generation at near-ambient pressure from solar energy. In addition, the system uses battery and ice-based thermal storage to support reliable 24/7 operation under variable solar conditions. The cooling units operate with natural refrigerants such as R-290 and CO_2, offering low global warming potential and avoiding persistent PFAS-related environmental concerns. Another innovative element is the PVmedPort, a mobile solar-powered health station for highly remote areas that can provide electricity, lighting, shelter, and support for vaccination services without requiring lengthy installation. The overall SophiA system is supervised by a smart SCADA platform that monitors environmental and operating conditions, balances energy flows, optimizes system performance, and provides continuous operational data for evaluation and improvement.

3. Field Demonstration and Technical Evaluation

The SophiA concept is being demonstrated at four representative healthcare sites in Burkina Faso, Cameroon, Malawi, and Uganda. These locations were selected to cover a broad range of climatic, infrastructural, and operational boundary conditions, enabling the system to be assessed under realistic off-grid and weak-grid healthcare environments. At each site, the implementation process begins with an evaluation of local energy demand, cooling and water requirements, existing infrastructure, and service priorities to adapt the system configuration to the specific needs of the healthcare facility. Following installation and commissioning, technical performance is continuously monitored through a network of sensors, data acquisition devices, and remote communication tools integrated into the SCADA platform. Key monitored parameters include solar electricity generation, thermal energy production, energy consumption, refrigeration performance at different temperature levels, thermal storage behavior, water production and quality, and overall system reliability.

This field-based evaluation provides practical evidence of the technical feasibility and operational robustness of the SophiA system in real healthcare applications. It also makes it possible to assess how effectively the integrated solar-based platform can maintain critical services such as vaccine preservation, medicine storage, sterilization, and clean water supply under varying environmental and usage conditions. The collected data support the identification of site-specific optimization measures, contribute to ongoing system refinement. In addition, local healthcare workers and technical personnel are trained in operation, monitoring, and basic maintenance procedures, thereby strengthening local ownership and supporting long-term sustainability. Through this combination of technical validation, continuous monitoring, and capacity building, the demonstration activities play a central role in verifying the scalability and practical relevance of the SophiA concept for remote healthcare infrastructure in Africa.

4. Key Innovations and Application Potential

The main innovation of the SophiA concept lies in the integration of multiple healthcare-critical services into a single renewable off-grid platform. Rather than addressing electricity supply, medical refrigeration, hot water provision, sterilization, and clean water treatment as separate infrastructure challenges, the system combines them into one coordinated and modular solution tailored to the needs of remote healthcare facilities. A further innovative aspect is the coupling of photovoltaic and solar thermal technologies within the same system architecture, supported by both electrical and thermal storage to improve reliability, increase solar energy utilization, and ensure continuous operation under variable weather conditions. This integrated approach enables the delivery of essential services with a higher degree of autonomy than conventional fragmented systems.

Additional innovation is reflected in the use of natural refrigerants such as R-290 and CO_2, which enable medical cooling at different temperature levels while minimizing environmental impact through low global warming potential and the avoidance of persistent PFAS-related substances. The concept also extends beyond electricity-based services by incorporating solar-driven thermal applications such as sterilization, laundry, and cooking, thereby reducing dependence on fossil fuels in healthcare operations. Another important element is the PVmedPort, a mobile solar-powered health station that can be rapidly deployed in highly remote areas and adapted for vaccination and basic healthcare support. The application potential of the SophiA concept is therefore considerable, as it offers a scalable and adaptable solution for rural hospitals, health posts, emergency response settings, and decentralized vaccination programs. Its focus on local manufacturing, local assembly, and capacity building further strengthens long-term maintainability, regional ownership, and the potential for broader replication across underserved regions in Africa and beyond.

5. Conclusion

The results show that the SophiA concept is a feasible and promising off-grid renewable energy solution for healthcare facilities in remote African contexts. By integrating solar electricity, thermal energy, medical refrigeration, water purification, and thermal end uses into a modular containerized design, the system addresses several critical service needs simultaneously. Demonstration activities confirm the practical suitability of the concept, while life cycle assessment indicates an environmental impact reduction of about 50% compared with conventional reference systems. These findings highlight the potential of integrated solar-based healthcare infrastructure to improve resilience, sustainability, and quality of service in underserved regions. The concept therefore offers a strong basis for future scale-up and adaptation to similar low-resource healthcare environments.

6. References

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