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ScienceDirect

Energy Procedia 57 (2014) 982 – 988

Energy Procedia

2013 ISES Solar World Congress

Construction of laboratories for solar energy research in developing countries

Henrik Davidsson[a]*, Ricardo Bernardo[a], João Gomes[b], Niko Gentile[a], Christian Gruffman[c], Luis Chea[d], Björn Karlsson[e]

[a]*Energy and Building Design, Lund University, Lund 221 00, Sweden*
[b]*Solarus AB, Älvkarleby 814 94, Sweden*
[c]*ÅF AB, Gävle 803 20, Sweden*
[d]*Universidade Eduardo Mondlane, Maputo, Mozambique*
[e]*Department of Energy, Building and Environment, Mälardalen University, Västerås 721 23, Sweden*

Abstract

A large number of photovoltaic systems have been installed in developing countries around the world during numerous projects. The goal is often to improve the quality of life in rural areas often lacking electricity. Many of these installations provide important services such as lighting and charging of various devices. However, when the projects are finished, there is a large risk that maintenance is not carried out properly and that malfunctions are never repaired. This situation can leave an otherwise well- functioning system unusable. A key problem is that there are not enough trained technicians that can maintain and repair the system locally. One reason for this is the lack of practical education in many developing countries. Furthermore, the availability of spare parts is essential for long term effectiveness.

During 2011 a group of researchers from Lund University in Sweden built a small scale laboratory in Maputo, Mozambique, with local researchers. The project was successful and today the laboratory functions both as a teaching facility and as a measurement station for solar energy research for licentiates, masters and Ph.D. students.

The main goal now is to widen the project in order to incorporate more universities in developing countries. We are now looking for new interested partners in developing countries who believe that such a laboratory could strengthen their ability to teach practical work and to perform research at a local university. Partners for planning and executing the project are also needed.

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Keywords: Sustainable Development; Solar Laboratory; Research and Education

* Corresponding author. Tel.: +46-46 222 48 51; fax: +46-46 222 4719.
E-mail address: henrik.davidsson@ebd.lth.se.

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Selection and/or peer-review under responsibility of ISES.
doi:10.1016/j.egypro.2014.10.081

1. Introduction

During 2006, foreign aid to developing countries amounted to over 100 billion USD. Over the last 50 years the total global sum is over 2.3 trillion USD [1]. The result of this foreign aid differs considerably as has been indicated in earlier studies [2, 3]. However, foreign aid is still necessary to stimulate investments and to decrease the gap between developing and industrialized countries [4]. Furthermore, drastic consequences can be expected if foreign aid is severely reduced. E.g., in Mozambique about 50% of the government budget is supported by foreign aid [5]. Thus, the discussion today is more focused on increasing the efficacy of the given aid. According to a 2012 estimate, about 1.6 billion people worldwide lack access to electricity. More than a third of this group is living on the African continent [6]. In Sub-Saharan Africa less than 25% of the population has access to electricity [7] and in Mozambique the number is only about 6% [8].The lack of electricity is one important reason for poverty [9]. Recent projects have largely been based on installations of stand-alone photovoltaic systems in remote areas. The effectiveness of this measurement is dependent on both local expertise and the availability of spare parts; two crucial points which are often disregarded [10]. Furthermore, the products needed are produced and imported from industrialized countries. Even if more people are given access to electricity the developing countries are left dependent. The absence of locally produced solar collectors and photovoltaic modules is not only related to a lack of funds but also to a lack of local, state of the art, scientific research and knowledge.

Lund University (LU) in Sweden has, for many years, cooperated with Universidade Eduardo Mondlane (UEM) in Maputo, Mozambique and the University of Zambia (UZ) in Lusaka, Zambia. Most of the cooperation has been with regard to Ph.D. students from the African countries coming to Sweden to gain knowledge and perform research. One of the main reasons for this is the lack of appropriate facilities in Mozambique and in Zambia to carry out state of the art solar energy research.

2. The past- what has been achieved

In order to intensify earlier cooperation and to further develop both the teaching and the solar energy research facilities, LU in Sweden has engaged in a project with both UEM and UZ. The project was built on the following three cornerstones:

Cooperation. Cooperation between the universities in Lund and Maputo and between Lund and Lusaka was established many years ago. However, cooperation between the two African nations has been limited. Introducing cooperation between them was one of the main objectives.
Research. A flexible, small scale laboratory for solar energy research was to be constructed in Maputo. The laboratory is intended to provide an opportunity to perform state of the art research regarding solar thermal and solar electricity. The laboratory should also become a new resource for education carried out at the university.
Education. New course material was to be developed within the project. The material should be possible to use as a course or as part of a future course given at the universities in Maputo and Lusaka.

Long term goals for the project and the constructed facilities in Mozambique were:

- To offer equipment, tools and knowledge to start local, scientific research. The installed equipment should allow general training for engineers even outside the field of solar energy, e.g. data logger programming for developers or improvement of the solar tracking system for mechanical engineers. In

the long run, this can have a positive effect on the number of trained technicians that can maintain and repair installed systems around the country.

- To provide national testing agencies for instruments and products that can start and use the laboratory. The laboratory will thus serve as a knowledge centre for solar energy research in the country.
- To replace some of the expensive instruments with cheap, and if possible, locally available and easily maintained equipment. The precision and accuracy of the equipment should only be reduced within an acceptable range. This is a difficult balance that has to be considered separately for each specific project.
- To provide local companies with an opportunity to work in close contact with researchers in order to develop systems and products for local markets. In the long run, this will hopefully create jobs and further research. This can also boost the attractiveness of engineering education in Mozambique.

The project was divided into two steps. Step one, i.e. the first trip, was focused on building the laboratory and giving solar energy courses at both UEM and UZ. Step two, i.e. the second trip, was focused on research and collector testing at UEM.

Step 1

The team from LU worked for three months in Maputo, starting in January 2011. During this period a small scale laboratory was built. The solar laboratory that was constructed consists of a small building equipped with a 250 l storage tank for hot water, a circulating pump, and a flow meter. These are shown to the left in Fig. 1. To the right in Fig. 1 are logging devices, radiation and temperature sensors. Simultaneously two collectors were installed for testing: one concentrating PV/T collector, and one concentrating thermal collector. Circulating copper pipes connect the collectors to the storage tank, while the sensors are connected to the data loggers. The laboratory can be used for collector testing, since the collectors can be easily replaced by other collector types, and for demonstrations for students The students can see the different collector parts on site and observe the measured parameters in real time such as solar radiation, ambient temperature, and inlet/ outlet collector temperatures and trace an IV curve from the PV/T collector. Figure 2 below shows a photo of the laboratory from the outside.

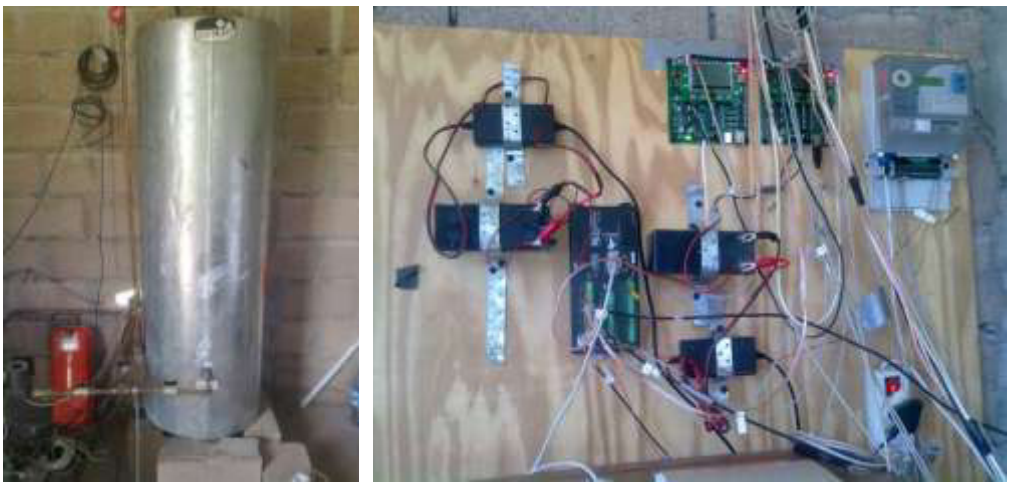

Fig. 1. Equipment inside the laboratory: (a) batteries, data loggers and wires from the sensors; (b) storage tank, circulation pump, expansion vessel, different valves and circulating ducts.

Fig. 2. Testing of a photovoltaic / thermal hybrid collector in front of the solar laboratory. The laboratory is located at the Universidade Eduardo Mondlane in Maputo, Mozambique.

During the first stay, a basic course on solar thermal and solar electricity was given to students at UEM and UZ. The course covered topics such as: solar angles and radiation, solar conditions in Mozambique/Zambia, solar collector physics and systems, optimization and cost analysis for local conditions. During the visit in Zambia the team included a researcher from UEM. The aim was both to strengthen teaching ability and to start cooperation between the two universities.

Step 2

The second visit to Maputo by the LU team was made at the end of 2011. The primary focus was on collector testing and carrying out state of the art research. During the stay, a M.Sc. student from the University of Zambia, Mr. Chabu Mumba, was engaged in the work as an exchange researcher. Mr. Chabu Mumba started his masters thesis while working in Maputo with local researchers regarding solar energy. Introducing such real, hands on cooperation between the universities was considered a major success for the project.

During the second visit to Maputo, a series of experiments were performed in order to investigate a concentrating PV/T hybrid solar collector. The PV/T collector was chosen due to a limited budget. The collector was sponsored by PV/T hybrid collector producer Solarus in Sweden. The collector investigated is shown in Fig. 2 above. Any kind of standard thermal collector or PV module can be tested in the laboratory with the installed equipment. Measurements were carried out simultaneously investigating measurement equipment at different price levels. The research performed resulted in two scientific publications: [11-12]. Bernardo et. al. and [11] research performed on the PV/T hybrid CPC-collector.

The effect of reflector edges, sharp acceptance angles and by-pass diodes introduces large variations in the electrical performance of an asymmetrical concentrating PV/T module. The impact on the electrical performance of the optical properties was measured in Maputo, Mozambique, as well as peak electrical power and its relation to cell/receiver temperatures. A detailed analysis of the contribution of the diffuse radiation to the total output was also carried out. In the second publication, related to the research carried out in the laboratory, Gentile et. al. [12] concluded that scientific research on solar energy can be carried out with low initial costs. The equipment cost can be reduced by up to 95% using alternative sensors with a drop in measurement accuracy of approximately 9%. The largest cause of reduced uncertainty is the sensor for the solar irradiance measurement. Other types of sensors should be tested in order to find optimum solutions for future projects. Gentile et. al. further concludes that involving local members from the early stages of the project is to be strongly recommended. It is also important to instil a sense of belonging and project ownership and to clearly state the long term goals.

3. Conclusions from the project

Five important conclusions were drawn from the project. Although more goals and ideas were discussed from the beginning these were the most important ones.

Recipients must take active part in the project. Planning the construction of the laboratory, the content of the courses and taking an active part in the building process of the research facilities, i.e. both the laboratory building itself and the installation of the necessary equipment are important steps to attain involvement. Building the laboratory and installing the measurement equipment not only results in an existing lab, it simultaneously educates the participating researchers and gives them a feeling of responsibility. The person who installs the data logger system becomes the local “logger expert “.

Recipients are allowed to carry out their own research, also in other fields. The flexibility of the lab to meet local requirements is fundamental. Flexible sensors and data loggers were chosen in order to meet these demands. Flexible equipment can be used for future research regarding, for instance, wind power or different combustion techniques. A flexible system allows the local researchers to develop products and systems for the local market that meet local needs.

Choosing affordable equipment with limited quality loss of the measurements is essential. Affordable equipment makes it possible for researchers to continue building and improving the laboratory even after the project is finished from the donor’s point of view. Simultaneously the equipment should be easy to work with.

The availability of spare parts such as sensors and electrical devices can be a problem in developing nations. Robust and easily replaced equipment is characteristic of this project. Choosing passive ways of cooling the equipment, for instance, renders a system with a low degree of disturbance.

Water is valuable, rare and expensive in many places. Furthermore, grid water is not always available. This should preferably not hinder the research. A closed water circuit boiler was planned for the solar thermal part of the project. In this type of system the energy can be lost at night by running it in a ground collector. Alternatively, the water can be used within the facility. Using the heated water or the electricity produced within the facility is in many cases important for educational purposes. Being able to physically show visitors the heated water from the system is beneficial. The hot water can be used as “proof” that the

technology works. The ability to be able to perform these kinds of interactive demonstrations was considered very important by the local researchers.

4. The future

The continuation of this project can take many different forms. Three main alternatives have crystallized as most likely.

- Continue building the same type of labs in the surrounding countries of Mozambique. This could, for instance, be Zambia, Botswana, Namibia or Tanzania. The project could involve cooperation between LU in Lund, UEM in Maputo and the new recipients. Including UEM in the project has many advantages. UEM has experience with building a new laboratory using limited resources. Knowledge of local customs and local conditions is certainly greater in the researchers from Mozambique compared to the researchers from Sweden or any other European nation. This is an advantage that should not be underestimated. Involving UEM could also potentially lead to cooperation between the universities in the involved countries in a very direct way. Active participation during the planning of laboratory building, installment of measurement equipment and planning of courses can serve as a solid platform for future cooperation. Furthermore, if the universities are working with similar equipment there is a clear benefit in exchange of knowledge and "know-how" if the research groups run into similar problems.
- Restarting a new project within a new country. This can in practice be anywhere in the world. The experiences and results from the project in Mozambique can be brought to the new project. The new country should be involved as early as possible in the planning. Common goals should be set for the project.
- Continuation of the project in Maputo with further technical developments and measurement capacities. Technical improvements such as installing stabilizers for the temperature output from the storage tank, a tracking system for the solar collectors, a cooling circuit for the storage tanks etc. can be installed. Continuing the work in Maputo would be beneficial in the sense that the structure and cooperation have now been well established.

We are now looking for new partners in developing countries who believe that such a laboratory could strengthen their ability to teach practical work and perform research at a local university. Partners for planning and executing the project are also needed.

Acknowledgements

The authors are very grateful to the Swedish International Development Cooperation Agency, Stiftelsen för utveckling av Energieffektivt Byggande, Gulbenkian Foundation and Maj och Hilding Brosenius Forskningsstiftelse for sponsoring the project.

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