ENERGY METER FOR CONCENTRATING SOLAR COOKERS TO INVESTIGATE CO2 REDUCTION AND USER ACCEPTANCE

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1. Abstract

A new type of energy meter used in concentrating solar cookers on the Argentinean Altiplano is described. The meters are used to quantify CO2 savings and the user acceptance. The installed meters measure the amount of energy that enters the solar cooker within a certain angle of acceptance. Only the direct fraction of the incoming sun light is measured. The acceptance angle of the metering device is adapted to the type of solar cooker and size of the cooking pot. The use of the energy meters gives valuable data on the particular use of each solar cooker. In CDM programs, this allows for the first time an exact determination of CO2 savings and pay out for each user according to the real emission savings. In poor regions, additional incomes out of CDM programs can be a strong argument helping the users in financing their solar cookers and so improving the diffusion of this technology. From 2007 to 2008 a first field test was carried out by EcoAndina with 50 installed SolCoDat metering devices. This measuring device might also allow additional income generation from CDM funds in small scale commercial projects where manually tracked concentrating cookers are used (e.g. small scale marmalade production) or gives information to which degree the product is produced by clean energy.

2. Introduction

Firewood is the main heat source in Andean villages on the Altiplano in Argentina, Chile and Bolivia. The energetic demand of the increasing population accelerates desertification in this semi-arid mountain region. Supported by private and public initiatives, 250 families in the Altiplano region in the province of Salta and Jujuy already apply an alternative heat source using parabolic solar cookers. These solar cookers are based on the design of the parabolic solar cooker SK14 (from EG-Solar) with an aperture area of 1.54 m² and thermal power of approximately 800 W. The cookers are manufactured locally and were adapted to the strong climatic conditions on the Altiplano. With these devices rural families can reduce their consumption of firewood by about 50 % /1/. This means, that instead of 600 kg of firewood per year and person the consumption can drop down to 300 kg. This saves labour and would avoid about 555 kg CO2 emission per year and person (non sustainable wood consumption assumed). Nevertheless, the initial costs of the solar devices are serious obstacles in the diffusion of solar energy in the Andean communities. In these communities, population lives in a subsistence economy (stock farming, little agriculture, small scale mining). Many of these areas are affected by social, economic and ecological problems. Until now, all the projects that took care of the diffusion of solar cookers depended to a certain degree on subsidies.

The clean development mechanism (CDM) created recently, can be a valuable instrument to promote alternative energy use in this sensitive mountain areas. Until now it was almost impossible that small rural communities could profit by the advantages of this mechanism. That is mainly due to the high adherent transaction costs of this mechanism and difficulties in determination of the exact quantity of emission reduced by each user. The introduced SolCoDat energy meters allow now, for the first time, to determine the true use of each solar cooker and the exact calculation of the pay off for each user. In poor regions, the additional income generated by CDM programs can be a great benefit that helps the users in financing solar cookers and so improving diffusion. From 2007 to 2008 in a first pilot project financed by the SEPS program, 50 energy meters were installed by the Argentinean Foundation EcoAndina.

3. Project

3.1. Functional principle

The SolCoDat 1.0 is a data collection system for concentrating solar cookers developed by the engineering office “hc-tronic” (www.hc-tronic.de). The Solcodat measures the amount of insolation energy that hits the solar cooker within a certain angle of acceptance. Basically it measures only the direct fraction of the incoming insolation. The sensor is a fotodiode BPW34 with a wavelength sensitivity of 400 to 1100 nm and a peak wavelength at 850 nm. The acceptance angle is defined by the distance between the fotodiode and the orifice window. The acceptance angle must be adapted one time to the type of solar cooker and the average size of the cooking pot. In the case of a parabolic solar cooker similar to the SK14, with a diameter of 1,4 m and a small 2 liter cooking pot, the distance is of 21 mm. The resulting acceptance angle is of +/- 4,5° which corresponds to 18 minutes of sun movement. After 18 minutes, the shadow begins to cover the sensor. After 50 minutes, the sensor is completely covered by the shadow. Every 30 seconds the signal of the sensor is measured by a microcontroller (8051). Every 30 minutes, the SolCoDat calculates an average value of the direct insolation, which is stored in the non-volatile memory. In order to determine the amount of solar energy Q captured in time t, the measured value of the direct insolation I_{dir} is multiplied by the aperture area A of the cooker and by the optical efficiency η_{opt}:

$$Q = \eta_{opt} \cdot A \cdot \int_0^t I_{dir} \cdot dt \qquad (1)$$

The thermal losses by convection and heat radiation must be covered in conventional stoves as well as in solar cookers. Therefore the energy saved in comparison to a conventional stove can be calculated using only the optical efficiency of the solar cooker.
The non-volatile internal memory can store 23,000 data values with 12-bit resolution. When an average value is stored in a 30 minutes interval, the total duration of the measurement is of 479 days. The SolCoDat can also be configured to measure the ambient temperature additionally. In this case, the total duration of the measurement will be half as long. The power consumption only amounts to 25 µA, for this reason the device can work up to 5 years with a single lithium battery. Due to long measurement capacity it is sufficient that a technician comes

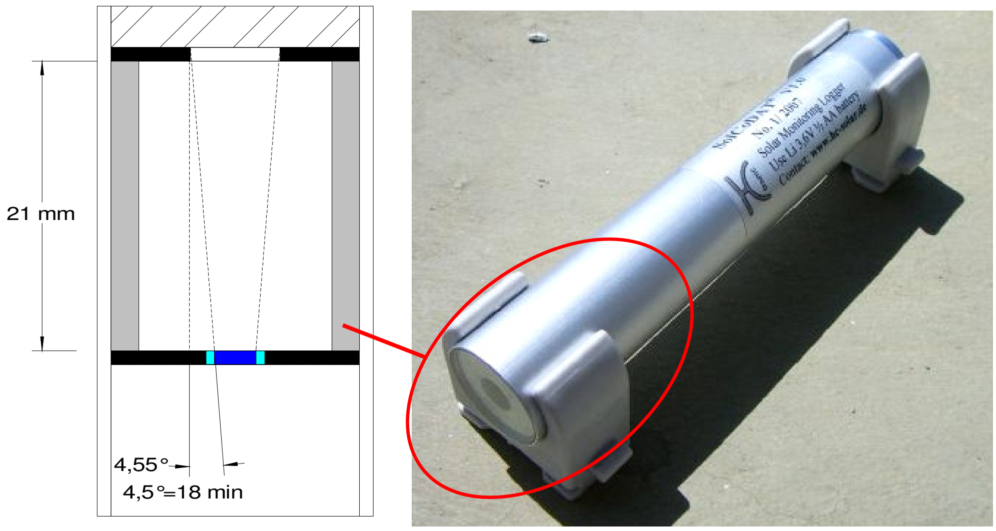

Fig. 1: Schematic of orifice and photo of SolCoDat

one time per year to read out the energy meter. When the data of the SolCoDat is read out with the supplied program, the integrated amount of insolation and gained solar energy captured by the cooker is shown in kWh/m ² and kWh. With these values, the avoided emission of carbon dioxide can be calculated comparing the saved energy with the energy consumption of a conventional stove driven by gas, wood or gasoline. This, together with CO2 certificates, makes it for the first time possible to pay out to the solar cooker user the amount that corresponds exactly to the avoided amount of CO2.
Additionally, a graphical presentation of the insolation and the temperature is obtained over the measurement interval. This allows a deeper investigation of the cooker use, the acceptance or detecting malpractice of the measuring device.
Theoretically a solar cooker might be oriented to the sun without use. There is no kind of control provided for this kind of malpractice. But if unheralded visits by the technicians uncover repeated malpractice the user must face sanctions. Nevertheless, the experience has shown that nobody does the work of orientating the cookers without using it since the amount resulting from CDM refunds is quite small.

3.2. Validation

The SolCoDat calculates the gained thermal energy with the product of the aperture area, the optical efficiency of the cooker and the direct insolation. The sensor this calibrated with a reference pyranometer in clear sky conditions, which is the most common climatic condition on the Altiplano. It is assumed, that black coloured pots are used. The optical efficiency was measured in experiments to vary between 45% and 60% dependent on the state of the reflector - if new or used, clean or dirty - (see table 1). The optical efficiency and the aperture area are adjustable parameters that are stored in the non-volatile memory of the SolCoDat.

Reflector condition	Optical Efficiency
new	60%
used, clean	51%
used, dirty	45%

Table 1: Optical efficiency and reflector condition (reflector: Alanod 318G2)

Figure 2 shows the energy measured by the SolCoDat with an acceptance angle adapted for a solar cooker in comparison to the heat input measured directly in the pot. The calculation of the heat input $\dot{Q}$ is estimated by the measured increase of water temperature in the cooking pot. This control method underestimates the real heat input at higher temperatures, because thermal losses by convection and heat radiation from the pot to the ambient are not being taken into account.

$$\dot{Q} = m_{H_2O} \cdot c_{p,H_2O} \cdot \frac{dT_{H_2O}}{dt} \tag{2}$$

In the experiment a cooking pot with 9 liters of water was used. At the beginning of the measurement at 11:50 the solar cooker was oriented perfectly to the sun. During the experiment, the cooker was not tracked, so the dependency of the heat input can be set in relation to the incidence angle of the sun. After a time of 35 minutes, the heat input begins to decline. After one hour and a half without tracking, the heat input reaches zero. The angle dependency of the SolCoDat corresponds satisfactorily to the measured thermal power reaching the pot, only at the end it gives higher results than the heat measured. On the other hand the thermal power calculated by temperature is underestimated at higher pot temperatures, so the SolCoDat behaviour corresponds well with the real acceptance angle of the cooker. With smaller pots a smaller acceptance angle would be necessary, because the focus leaves the absorber area on the pot faster.

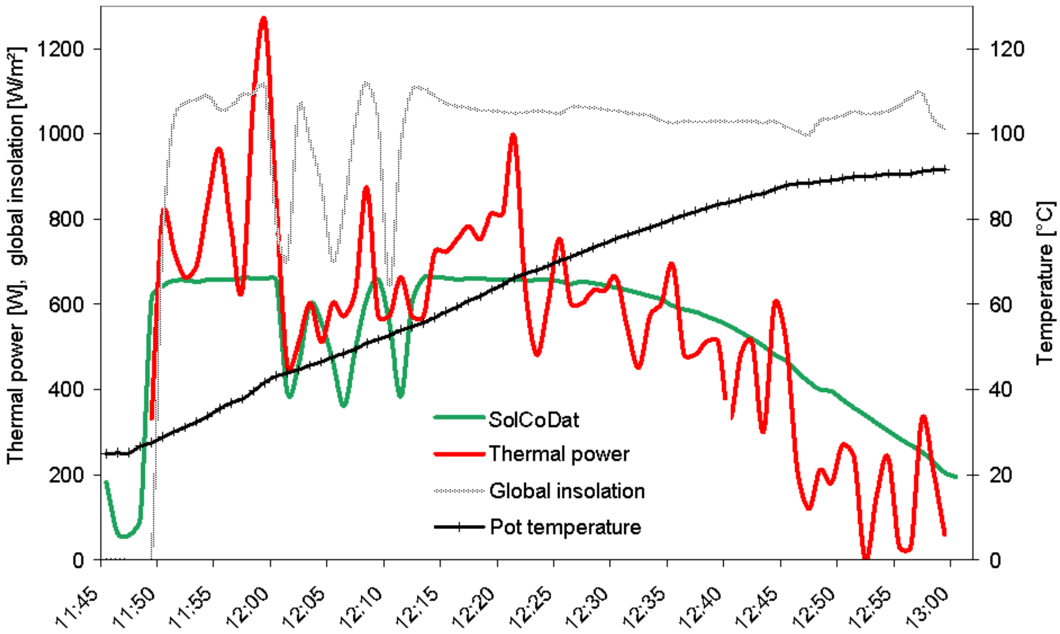

Fig. 2: Validation with solar cooker (type SK14)

The SolCoDat is fixed to the solar kitchen by clamps in such a way, that the sensor window is located in the aperture plane of the cooker. Figure 3 shows a woman on the Argentine Altiplano owning a solar cooker with an installed SolCoDat device. The first tests with users on the Altiplano have shown promising results. Figure 4 shows the solar energy gained by two families during a period of 6 weeks. Family 1 gained in average 3,7 kWh per day and family 2 gained 3,08 kWh per day. The maximum values reached up to 6,7 kWh/day when the cooker was used for more than 9,5 hours per day. Also it can be seen, that the cooker had an intense use during the first week after the installation of the SolCoDat, which can be attributed to enthusiasm at the beginning of the project.

Fig. 3: SolCoDat attached to a solar cooker

An investigation of the logged data by calculating the average hourly usage, demonstrates that the main use of the cooker is during noon between 12:00 and 13:00. Figure 5 shows the average use of the solar kitchen over a day in 30 minutes resolution. While family 2 intensively uses the cooker during the morning and noon but little in the evening, family 1 only uses the cooker for a short time at breakfast and more during noon and afternoon.

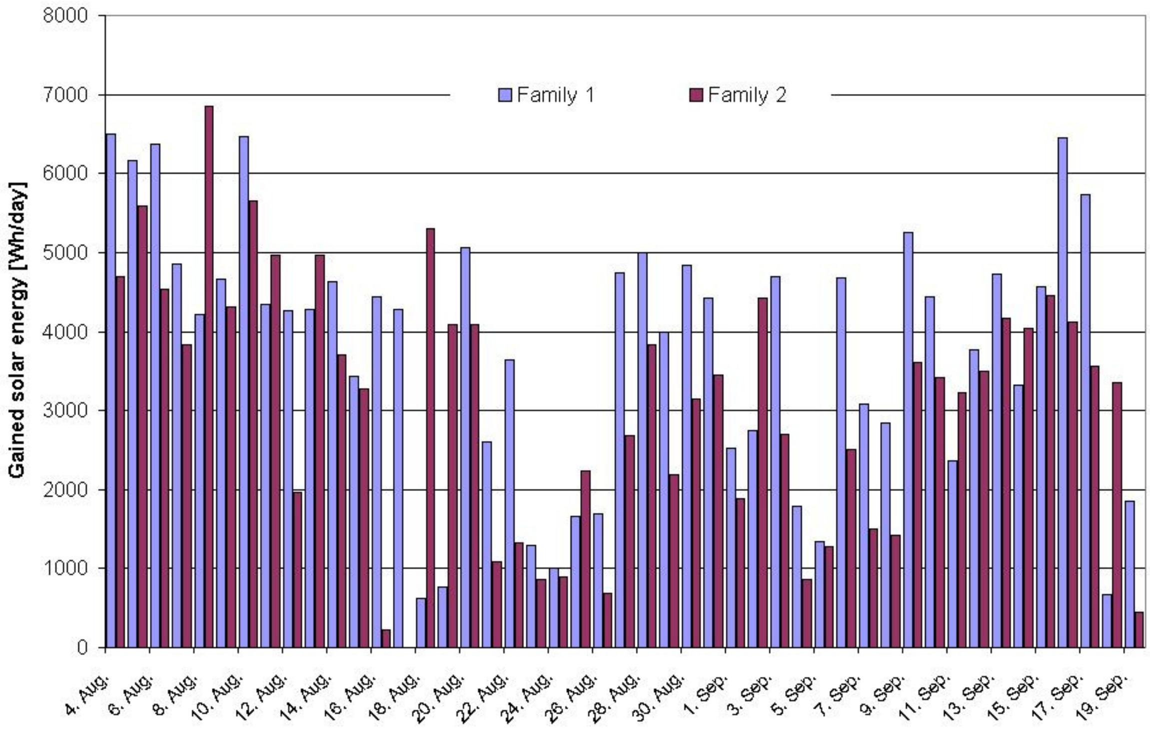

Fig. 4: Solar energy gains by two families on the Argentine Altiplano during 6 weeks

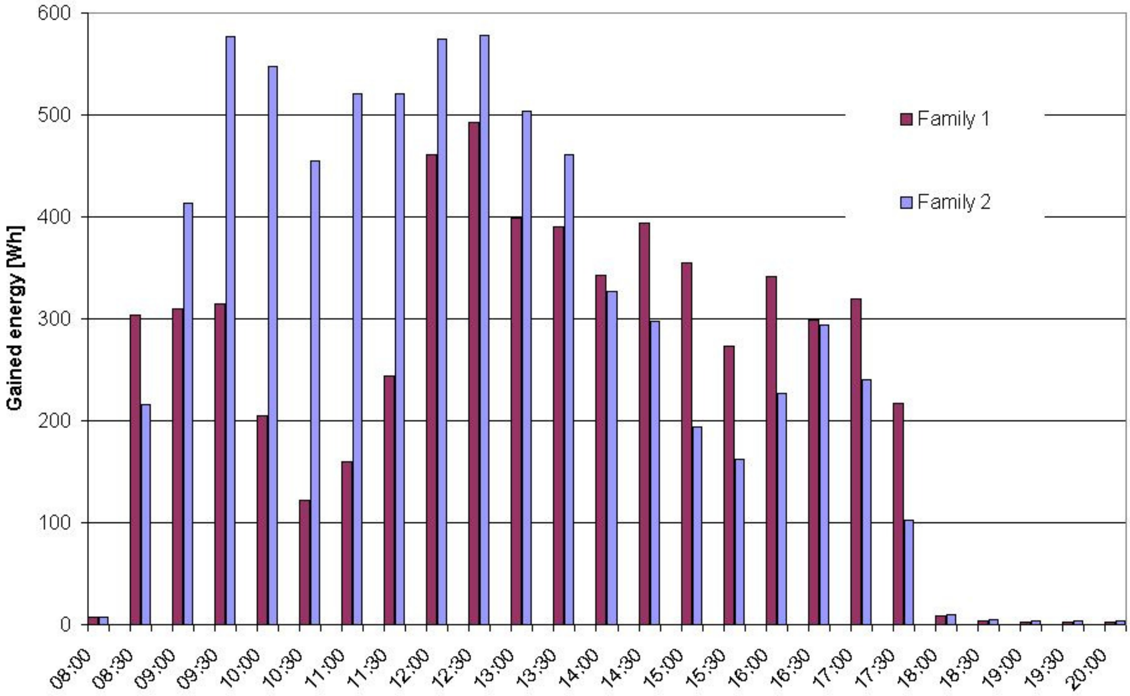

Fig. 5: Average daily use of the solar cookers resolved in hours

4. Conclusion

The use of SolCoDat energy meters, allows determining the real use of each solar cooker and in CDM projects the most exact remuneration for each participant. The measurement of solar energy gains still depends much on factors which are difficult to specify like the quality of the reflectors, the size and the colour of the pot. But at the same time, the SolCoDat represents one of the most exact and suitable methods at the moment available for a complete and extensive monitoring of concentrating solar cookers. This is also due to its robust design and low price. An alternative to this method could only be an acceptance study, which implies a great effort of time and resources. Another big disadvantage of an acceptance study is that it grants a fixed average remuneration for each participant, which is not in direct relation with the real avoided CO2.

The measurement results have shown that each family can save in average 3 kWh per day with its solar cooker. Regarding the calculation of avoided CO2, this amounts to an equivalent of 1,9 tCO2 when using a woodstove (20% efficiency) or 0,58 tCO2 using a gas stove (40% efficiency) /2/. Depending on the replaced stove type, the average refund from CDM certificates can reach 8 to 26 Euros per participant and year (assuming 1 tCO2=15 Euro). In poor regions this additional income from CDM programs helps users to finance their solar cookers within a few years only by cooking with it, improving diffusion. During the next months, the SEPS-project, which ran over 21 months, will end and more data on the acceptance and the saving of CO2 will be evaluated.

REFERENCES

/1/ C. Mueller, “USO DE COMBUSTIBLE VEGETAL Y SU DIMINUCIÓN MEDIANTE APROVECHAMIENTO DE ENERGÍA SOLAR”, study for Fundación EcoAndina, 1998 (see at www.hc-solar.de).

/2/ CDM – SSC WG, “Indicative simplified baseline and monitoring methodologies for selected small-scale CDM project activity categories”, Eleventh Meeting Report, Annex 01, I.E./Version 01, Sectoral Scope: 01