Solar water heater with thermosyphon circulation

Bernd Sitzmann,
Ökozentrum Langenbruck
Centre of Appropriate Technology and Social Ecology,
Langenbruck (CH)
2003

Information & Knowledge Management

Technical Information
- ■ **Energy / Environment (E)**
- ☐ Water / Sanitation (W)
- ☐ Agriculture (A)
- ☐ Foodprocessing (F)
- ☐ Manufacturing (M)

This *module* is available in:
- ■ **English** (e)
- ☐ French (f)
- ☐ German (g)
- ☐ Spanish (s)
- ☐ Other:.............................

File: E021E_solarwaterheater.pdf

1 Introduction

In comparison to conventional hot-water heating systems, Solar water heaters (SWH) can represent an alternative with moderate costs in countries with high energy costs and sufficient irradiation.
While having significance for the supply of energy in these countries, the introduction of these new but simple techniques also opens up possibilities for sustainable socio-economic development.

The circulation of the heat carrying fluid in the SWH described here is effected by the difference of density between the warmer liquid in the solar panel and the colder liquid in the storage tank. Therefore, no electrical pumps or control equipment are needed.

Due to their simple nature, these SWH can be produced by local craftsmen. Because of this, investment costs for the set-up of a SWH can be reduced and a SWH can become a cost-effective alternative to conventional hot-water tanks. SWH are used mainly in hospitals and hotels in developing countries. However there are also market opportunities in urban surroundings with increasing standard of living. Projects on SWH carried out in Zimbabwe [1] and Puerto Rico [3]have already shown successful implementation and stable market conditions for SWH. At present the Ökozentrum Langenbruck accompanies partners in Eritrea in setting up the local production of SWH.

2 Feasibility study on SWH

Planning the introduction of SWH in the corresponding partner countries requires a thorough feasibility study for economical and technical clarification.
The most important technical parameters are the meteorological conditions which are available as weather data [2].

For the thermal use of solar energy such as in SWH, mainly direct radiation (being part of global radiation) can be used for energy production (Fig.1). Therefore, the ratio between diffuse and direct radiation in the area in question has to be checked carefully. Diffuse radiation resulting from dust, mist and cloudy conditions can - despite high values of global radiation – hamper the economical feasibility of SWH in tropical and subtropical regions and has to be taken into account.
Another important consideration is the occurrence of frost periods in the area. If frosts do occur, the SWH has to be operated with a mixture of antifreeze to water at a ratio of 1:3. In this case the hot-water storage tank must be put inside the building which will raise costs. In regions which experience frosts, the use of a pump-driven collector circulation and placing the storage tank in the boiler room may be preferred.
High wind speeds and low ambient air temperatures usually require the collectors to be covered with glass, especially if high demands with regard to hot-water availability and temperature exist. The use of hardened glazing for solar collectors,

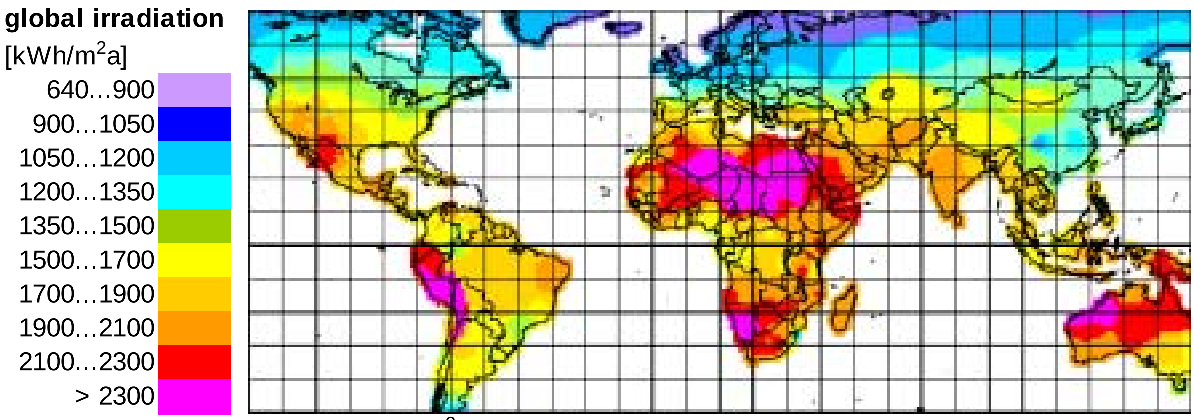

Fig. 1: Global irradiation in kWh/m^{2}a [7]

with high transmission and low emission of radiation, is preferable for SWH but costs more than conventional glass. Conventional glass can only be used if no hailstorms which can destroy the glass are known in the region. Alternatively, a protective barrier made of metal grating can be used to protect the glass by reducing the impact speed of hailstones, but this also increases the investment costs of the SWH.

The pH value of the water must be taken into account when constructing a SWH. Ground water with a strong deviation from neutral pH 7 can influence the corrosion of various components heavily and lead to the early destruction of the SWH. In these regions the direct flow of drinking water through the collector (open system) should be avoided.

Using meteorological data the gross solar heat gain of the SWH can be calculated. The economical efficiency of a SWH can be estimated from the energy savings made possible in comparison to a conventional system.

Two factors are considered to analyze the economic efficiency and market potential of the SWH. First, the amount of energy saved and corresponding financial savings have to be calculated. Second, the repayment time for the investment costs has to be calculated from the savings made possible through the use of solar energy instead of conventional energy. Table 1 shows a comparison of the economic efficiency of SWH for the countries Eritrea and Kosovo. The Gross solar energy gain is calculated by:

Q_{use}= optical efficiency * f_{loss} * G_t

Table 1: Economic efficiency of SWH in Eritrea and Kosovo

	Eritrea	Kosovo	Unit
Energy cost per kWh (electric)	0.11	0.08	EUR./kWh
Daily global irradiation G_t	5.5	4.0	kWh/m²
Yearly global irradiation	2008	1470	kWh/m²*year
Coll.- efficiency (x=0.05)	0.6	0.6	%
Collector area	2	4	m²
Energy losses in pipe system f_{los}	0.15	0.15	%
Gross solar energy gain Q_{use}	1877	2749	kWh/year
Savings in electric energy	200	220	EUR/year
Costs of a 2m^2 – SWH	630		EUR
Costs of a 4m^2 – SWH		1800	EUR

3 Engineering

The SWH described here charge the storage tank by means of a gravity-driven circulation. This means that the circulation of the energy transporting fluid is effected by the difference in density between the hotter fluid in the collector and the colder fluid in the tank situated above the collector.

gate Information Service / gtz, PO Box 5180, 65726 Eschborn, Germany
Phone: +49 (0)6196 / 79-4214, Fax: +49 (0)6196 / 79-7352, Email: gate-id@gtz.de, Internet: http://www.gtz.de/gate/

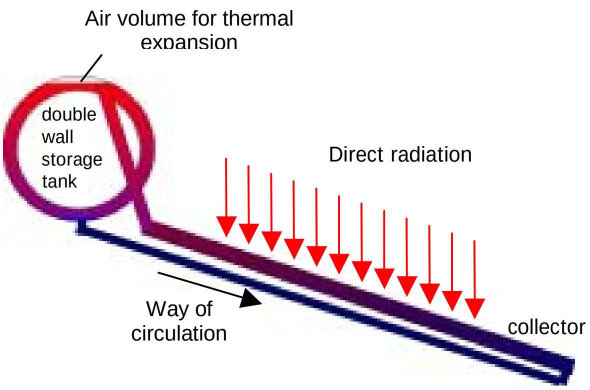

Fig. 2: Gross section of a SWH.

The storage tank may be oriented horizontally of vertically. With regards to the optimal temperature layering (stratification) of the water in the tank, the vertical arrangement has some advantages, but the installation is often more costly to set up.

3.1 Inclination of the SWH

When constructing and installing the SWH it has to be assured that circulation of the heat carrying fluid does occur. As a basic principle, SWH in general, but gravity circulation systems especially should avoid the formation of air pockets in the collector circulation. Also, all pipe diameters have to be dimensioned large enough to minimize losses though friction. The inclination of the connecting line between collector and tank should be at least 8^o. Equally important is a slight horizontal inclination (1-2^o) of the collector in direction of the upper exit point of the collector, this in order to avoid the formation of air pocket in the corners of the collector.
A vertical inclination of 8^o is based on experience but is also documented thoroughly in literature[6].
The optimal vertical inclination of the collector is also determined by the regions latitude. Close to the equator, the sun's rays hit the ground almost perpendicular all year round, making but little inclined collectors favorable. In contrast, the situation in central Europe asks for an optimal angle of installation of about 30^o.

The detailed calculation of the inclination of a SWH in a gravity-driven system is quite complicated. However, it can be simplified using limit values of collector temperature and volume flow for water as the heat carrying medium.
The circulation is being effected by the different densities (Tab.2) in the supply ρ_v and return ρ_r run and by the difference in height h. The amount of difference in static pressures Δp determines how fast the system will work.
The moving water meets resistance caused by friction with the pipe's walls, bends, the tank, fittings etc.

$$\Delta p = \Sigma.(p'.l) + \Sigma\, p_n$$

The pipe resistance *p*' is the force (in Pa) per meter which will slow down the flow of water in the pipe. In addition to the resistance caused by the pipe wall, the resistance of each single resistance factor p_n such as bends, junctions and special mountings has to be calculated. The corresponding values for *p*' and for p_n are usually given in diagrams or tables [4], [5].

If the resistance is greater than the pressure resulting from temperature difference and height of the different water bodies, the system will not work. The speed of water movement will increase until equilibrium between the pressure and the total resistance of the system is reached.

Tab. 2: Density of Water at different temperatures.

Temperature [°C]	Density [kg/dm³]
0	0.9998
10	0.9996
20	0.9982
30	0.9956
40	0.9922
50	0.988
60	0.9832
70	0.9777
80	0.9718
90	0.9653
100	0.9583

gate Information Service / gtz, PO Box 5180, 65726 Eschborn, Germany
Phone: +49 (0)6196 / 79-4214, Fax: +49 (0)6196 / 79-7352, Email: gate-id@gtz.de, Internet: http://www.gtz.de/gate/

3.2 Equalizing pressures in the SWH

The collector has to be safeguarded against thermal expansion of the heat carrying fluid. Otherwise, there is danger that the installation is destroyed prematurely though compressive stresses. The collector circulation has to be able to respond to short-time differences in density by means of an expansion vessel. In addition, a safety valve must protect the SWH from stepping over the maximum permissible pressure of the installation. The short-time differences in densities may be compensated for by expansion vessels which are available on the market for this purpose, or, more simply, by a volume of air which is present in the collector circulation and which is capable of compensating for any thermal expansion. This air volume can be calculated from the volume of the heat carrying fluid in the collector circulation, the initially charged pressure and the maximum permissible installation pressure:

$$V_{exp} = V_e \cdot (p_e+1) / (p_e-p_a)$$

$$V_e = V_{SWH} \cdot f_{exp}$$

V_{exp} Air volume [m^3]
V_e Expansion of volume [m^3]
p_e maximum pressure [Pa]
p_a pressure at 20°C [Pa]
V_{SWH} Total volume in the collector and jacket of the tank [m^3]
f_{exp} Thermal expansion factor of water (0.036 for ΔT of 90°C).

In SWH in which the water flows directly through the collector there is no need for any expansion facilities since thermal stresses can be led away directly through the sanitary pipes. Still, a safety valve should also be installed in these installations since sudden pressure changes in the sanitary pipes can lead to the destruction of the SWH.

3.3 Installation and placement of SWH

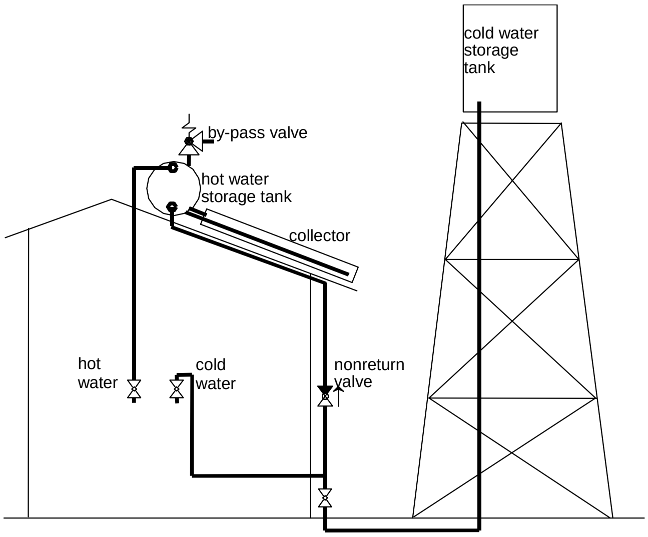

Fig. 3: Installation of a SWH in existing water supply.

When possible, the SWH should be installed directly above the hot-water consumer. By doing so, long piping lengths and the corresponding energy losses can be avoided.

Before installing the SWH, the roof construction has to be checked for stability. If necessary, a sub-structure has to be set up to reinforce the roof construction. Any shading from buildings or trees close by (which will lower the energy yield of the SWH) has also to be accounted for.

If a SWH is connected to an elevated water storage tank (Fig. 3) it has to be checked whether the storage tank can supply enough pressure to fill the SWH. Especially if the SWH is installed on the roof the height difference between SWH and elevated storage tank has to be reviewed.

A nonreturn/check valve should be mounted on the cold water supply pipe coming from the elevated storage tank. This will avoid draining of the hot-water tank in case the elevated storage tank runs empty. Otherwise, if the hot-water tank is emptied, air will enter the pipe system which will require the whole installation to be purged of air.

The pipe carrying the hot-water away from the hot water tank should be insulated, at least outside the building, even if a warm climate prevails. Otherwise, substantial energy losses can occur through the connecting pipes.

3.4 Corrosion

Installation of SWH on metal roof
Electrochemical corrosion of parts of the SWH through contact with other metals such as copper and zinc has to be avoided when installing the SWH on a metal roof. If metals with unequal electrochemical potential are screwed together, a spacer of e.g. rubber has to be used to avoid direct contact of the two metals.
Copper pipes for installation
The same is true for the installation of water pipes: if copper pipes are used together with galvanized steel pipes the two metals have to be separated electrochemically by a brass adapter. Downstream from a copper pipe, no galvanized steel pipe should be installed since copper ions will reach the zinc with the water and corrode it.

In order to avoid corrosion of a SWH, a closed circulation system is advised. Especially if copper is used as heat absorbing material there is danger of electrochemical corrosion in an open system.
Corrosion can also occur in the cracks and crevices of an improperly constructed hot-water tank. To avoid these cracks, the body surface of the tank has to be constructed of rounded parts, bluntly welded together to form the tank.

4 Techniques of construction

4.1 The collector

The solar collector consists of a copper absorber which transports the energy of the solar radiation from an absorbing lacquer to the water. The absorber is insulated against energy losses by glass on the front and an insulation layer in the back. If warm climatic conditions prevail, the glassing and insulation may be

Fig. 4: soldering of the absober on the soldering table.

unnecessary. As shown in Fig. 5, no bends which will allow siphoning should be present in the absorber of a gravity circulation system.

Securely connecting the absorber pipes with the collecting pipes at each side of the absorber is achieved using a special enlargement tool and hard soldering. The absorber pipes are soldered to the absorber sheet metal using a custom-made soldering table (Fig. 4) which allows to press the pipes down on the sheet metal for subsequent soldering.
When doing so, care has to be taken to heat up the absorber in a regular fashion. Otherwise, thermal stress will make the sheet metal bend and corrugate.
For insulating the collector, a material has to be used which does not release any of its constituents when heated up. These vapours can precipitate on the inner side of the glazing and greatly reduce the efficiency of the collector. The suitability of an insulating material can be tested quite simply by heating a sample of the material in a cooking pot and watching if any

gate Information Service / gtz, PO Box 5180, 65726 Eschborn, Germany
Phone: +49 (0)6196 / 79-4214, Fax: +49 (0)6196 / 79-7352, Email: gate-id@gtz.de, Internet: http://www.gtz.de/gate/

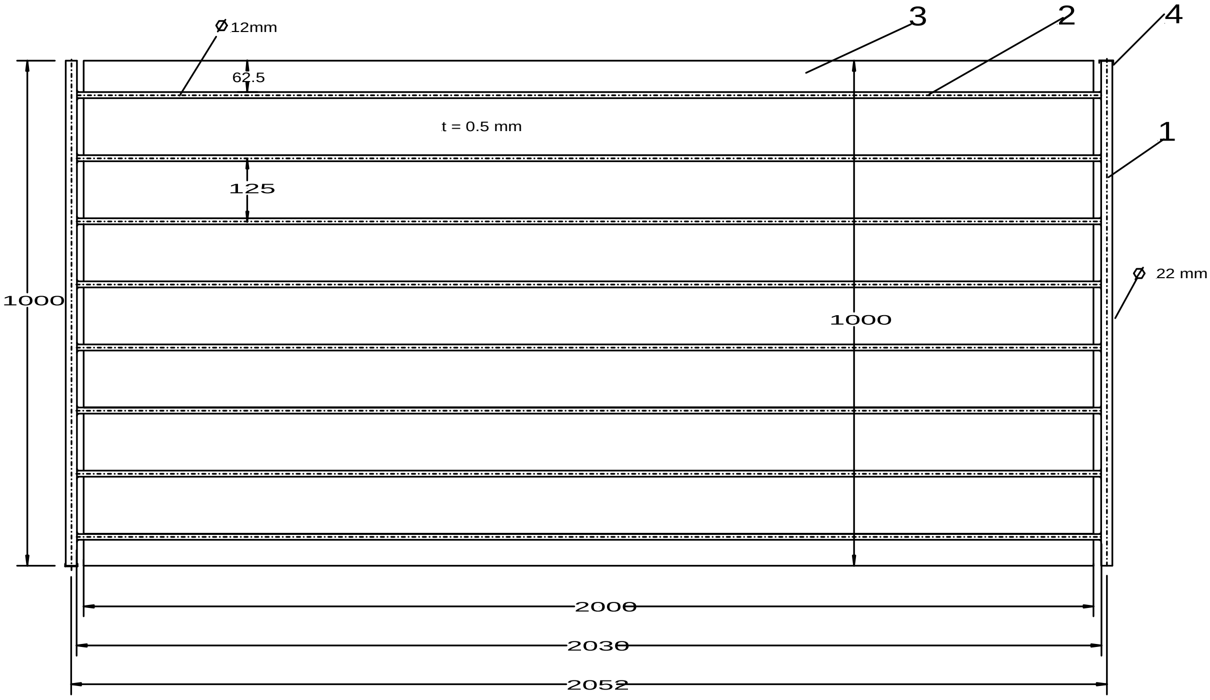

Fig. 5: Design of a 2m^2 –absorber.

precipitation occurs on a piece of glass which covers the pot. The choice of the proper glazing was already discussed in chapter 2.
The collector can be assembled using a simple construction of metal sheet. For reinforcement of the frame, wood can also be used.

4.2 The hot-water tank

Hot-water tanks are usually constructed of steel with enamelled or synthetic inner surface coating. At times plastic tanks are also used, but these have to suffice the same high demands on temperature resistance as steel tanks [1]. Steel tanks are often protected additionally against corrosion using a sacrificial anode.

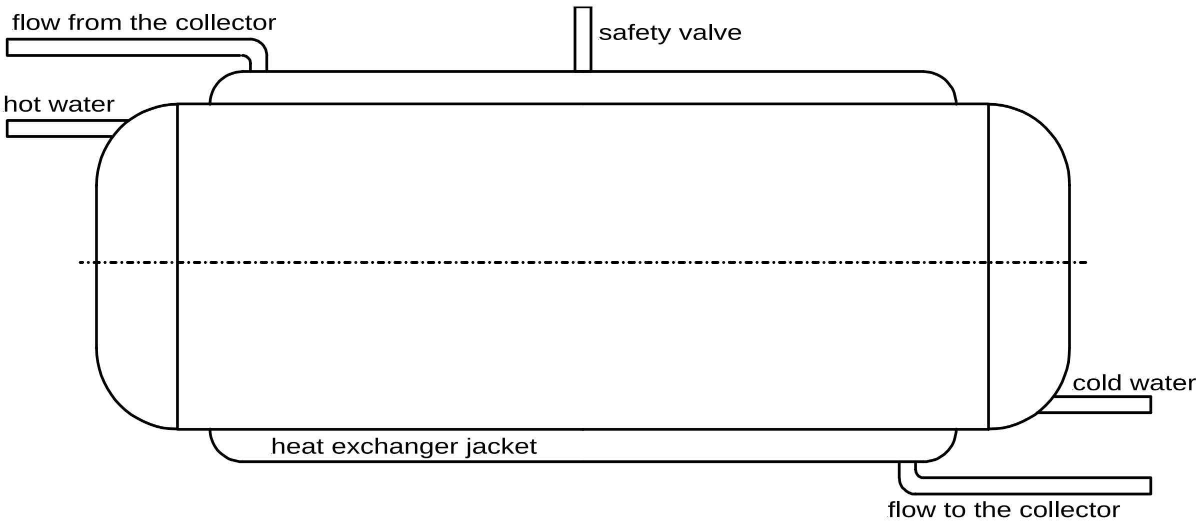

Fig. 6: Drawing of a hot water tank

gate Information Service / gtz, PO Box 5180, 65726 Eschborn, Germany
Phone: +49 (0)6196 / 79-4214, Fax: +49 (0)6196 / 79-7352, Email: gate-id@gtz.de, Internet: http://www.gtz.de/gate/

Usually, magnesium is used as the sacrificial anode which will corrode before steel. Corrosion can also be avoided by a properly constructed tank which is free of cracks and crevices (see chapter 3.4 and Fig .6).
All pipe connections to the tank have to be led down after leaving the tank since otherwise, internal circulation in the connecting pieces will cause a constant loss of energy. The tank has to be protected against energy losses (especially at night) with locally available insulation material.

5 Dimensioning of the SWH

The dimensions of the installation to be built is mainly dependent on the daily demand for hot-water and the radiation on the collector area. The optimal position of the installation often has to be adjusted due to roof construction and shading, yet usually a solution can be found.
At an optimal southern alignment and the proper inclination, the solar gross heat gain can be calculated as follows:

$$Q_{sol} = A_{Coll} \cdot H_{Gh} \cdot \eta$$

Q_{sol}: Solar gross heat gain of the SWH [kWh/a]
A_{Coll} : Area of the collector [m^2]
H_{Gh} : Global radiation on the inclined area [kWh/m^2a]
η: Optical efficiency of the solar collector

The amount of energy which is required can be calculated from the hot-water consumption for a year, the difference in temperature between cold and hot-water and the heat capacity of water:

$$Q_{HW} = m \cdot c_p \cdot \Delta T$$

Q_{HW}: Energy needed for water heating [kWh/a]
m: Consumption of hot-water per year [kg/a]
c_p: Heat capacity of water [kWh/K kg]
ΔT: Temperature difference for water heating [K]

In reality, the area of the collector field is usually a matter of the available financial means. Especially in temperate regions with little solar irradiation, a fraction of 60% of total energy demand for hot-water heating to be covered by solar energy is seen as optimum. To provide for 100% of the energy needed with solar energy is only reasonable in southern countries with high solar radiation and favorable climate.

In southern countries, the size of the tank can be dimensioned as to contain the amount of hot-water needed for one day. In northern countries, the tank size should allow the bridging of three days of unfavorable weather, which means a tank of about 500 to 700 liters for a single family detached house.

6 References and further information

[1] W. Weiss, A. Schwarzlmüller: Solar energy co-operation Austria – Zimbabwe A contribution to sustainable development. Syposium on renewable energy in developing countries, Basel, Switzerland 2002
[2] Meteonorm, Version 4.0, Meteotest, Bern 2000
[3] O. Headley, Barbados Employs the sun to heat water, Inforse Sustainable Energy News, No. 30, Aug. 2000
[4] H. Recknagel, E. Sprenger, W. Hönmann; Taschenbuch für Heizung und Klimatechnik; Oldenburg Verlag, 1987, München
[5] H. Appold, A. Schulze-Oechtering, Fachkenntnisse Zentralheizungs und Lüftungsbauer, Verlag Handwerk und Technik, Hamburg 1992.
[6] H.Ladener, Solaranlagen-Planung, Bau + Selbstabu von Solarsystemen zur Warmwasserbereitung und Raumheizung, Ökobuch Verlag, Staufen bei Freiburg, 1996.

6.1 Institutions and Organisations

Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, German Appropriate Technology Exchange-GATE Information Service
P.O. Box 5180, 65726 Eschborn, Germany
Phone: +49 (0)6196 / 79-4214
Fax: +49 (0)6196 / 79-7352
Email: gate-id@gtz.de,
Internet: http://www.gtz.de/gate

Ökozentrum Langenbruck
Centre of Appropriate Technology and Social Ecology
Schwengistrasse 12, 4438 Langenbruck
Switzerland
Phone: +41 (0) 62 387 31 11
Fax: +41 (0)62 390 16 40
Email: admin@oekozentrum.ch
Internet: www.oekozentrum.ch

Arbeitsgemeinschaft ERNEUERBARE ENERGIE
Institut für Nachaltige Technologien
Postfach 142, A-8200 Gleisdorf, Austria
Phone: +43 (0) 3112 58 86
Fax: +43 (0) 3112 58 86 18
Email: office@aee.at,
Internet: www.aee.at