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Cumulative Energy and Emission Balance of Large Solar Heating Systems

Eric Hahne, Boris Mahler, Holger Rebholz
University of Stuttgart
Institute of Thermodynamics and Thermal Engineering,ITW
Pfaffenwaldring 6, 70550 Stuttgart
E-Mail: pm@itw.uni-stuttgart.de

Abstract

The savings of solar energy installations are often disputed with respect to money, energy and emissions. In order to give a better insight, the various processes related to the production and operation of a large solar heating system are investigated. Material masses and operation data were obtained from a big housing project which we had planned and which is in operation; energies required and emissions were taken from literature.

The most consumptive components were found in the seasonal storage container, the collectors and their supports on the roofs.

Keywords: solar heating, cumulative energy consumption, cumulative emission.

1. Introduction

Solar heating systems are usually judged by the amount of fossil fuels which is saved and by the amount of air pollution which is prevented while these systems are used. Energy for operating such solar heating systems is usually not taken into consideration as well as the extra pollution in the production processes of the required machinery and materials.

A balance of energy saving (Eyerer 1996) due to solar gains in a certain time on the one hand and energy expenditure on the other, provides - in economical terms - the amortisation period required to pay back what was invested. This is called the energy payback time. Only when this time has passed, the solar heating system starts to save fossil fuel energy. In the same way, the reduction of air pollution can be treated.

Such a comprehensive energy and emission balance should provide a more realistic picture in the often ideological discussions on solar energy. For a total balance, the energy and emission expenditure for dismantling the system and recycling the components should also be included. Emissions could be transferred into energy demand by considering the energy required to transfer polluting matter into non-polluting. Neither dismantling nor pollution transfer were considered here because of lack of pertinent data.

Our comprehensive balance comprises: the materials, the construction of the components, their transport and finally the utilization of the system. The energy demand for these processes is accumulated and presented as Accumulated Energy Comsumption (AEC).

The air pollution is differentiated in emissions contributing to the Global Warming Potential (GWP) (CO_2, CO, CHu N_2O); which are presented in CO_2-equivalents, and in pollutants like SO_2, NO and dust, which are presented as SO_2-equivalents.

For this study (Rebholz 1997) we used an existing installation: a large solar assisted district heating system in Friedrichshafen in the southwest of Germany. Heat for warm water and house heating has to be provided for 568 apartments. A collector area of 5 600 m^2 and a 12 000 m^3 hot water storage container, made of concrete, are supposed to cover 50 % of the demand, the rest shall be covered by gas heaters - primarily in the winter months. The first stage of this housing project with half of the apartments and half of the collector area has been in operation since 1996. The project was planned by ITW and is also monitored by us now. A sketch is given in *Figure 1*.

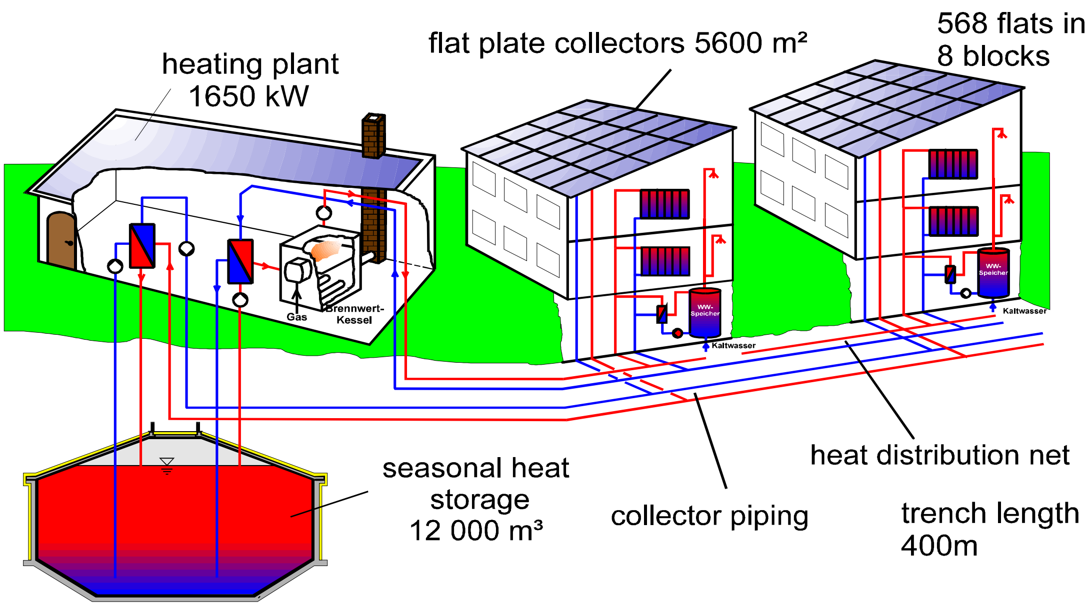

Figure 1. Sketch of the Friedrichshafen solar heating system.

TABLE I. Comparison of Utilized Recources for Electric Power Production in Europe and the State of Baden-Württemberg.

	European Mix %	Baden Württemberg %
Coal	18	29
Hydro Power	15	8
Lignite	11	-
Natural Gas	10	5
Nuclear Power	36	54
Oil	10	3
Others		1

2. Procedure

We have to be aware that data and information on comprehensive balances are scarce.As far as these are available, they often represent special projects in a certain environment and at a certain time. While the production of materials may be comparable, the utilization of energy for the production may not be comparable. A comparison of resources utilized for electric power production is shown in TABLE I. Here we used the European mix

On the basis of construction plans, call for tenders and final payments all the materials applied in the solar heating components i.e. collectors, piping, storage tank were taken into consideration. For the materials we considered the energy demand for: mining of the raw materials, their transport to the production sites and the production. The most relevant materials here are: aluminium, concrete, mineral wool and steel.

Using the data base of Frischknecht (1994) and the user interface "IO-table (IO Tabella 1995)" energy and emission information on the materials was obtained. Information on energy demand for transportation and production were obtained from interviews with respective firms.

3. Results for the Accumulated Energy Consumption and Emissions

3.1 Results for the production of the solar system

The Accumulated Energy Consumption (AEC) for the production of the solar system was obtained as 9 030MWh. In column (a) of TABLE II this energy demand is split into the shares of the various components

The largest share is for the concrete container for the seasonal storage with 46 %; solar collectors require 31 % and the supporting structure for these collectors on the roofs 15 %. All other AEC‘s e.g. for piping (5 %) and the extra facilities (heat exchanger etc.) in the central heating plant (3 %) are small. Detailed results for the various components are given by Rebholz (1997).

TABLE II. Share of the Production of Various Components of the Solar Heating System and Total Amounts.
(a) Accumulated Energy Consumption (AEC) (b) Global Warming Potential (GWP)
(c) SO_2 emission

Share of the production of various solar heating components	(a) AEC %	(b) GWP %	(c) SO_2 %
Seasonal storage	46	52	57
Supporting structure	15	15	5
Solar collectors	31	25	29
Collector piping/roof	2	2	1
Collector piping/ground	2	2	1
Central heating plant	3	3	5
Piping to the storage	1	1	2
Total amount	9 030 MWh	2 216 tons	22 tons

The effect of production of the solar heating components on air pollution and global warming was also considered The various gases (CO_2, CO etc.) have different global warming potentials (GWP). Accordingly their amount was multiplied by a specific factor and summed up in order to give a so called CO_2-equivalent.For air pollution, the formation of SO_2 ,due to sulphur content of the fuel used to produce power and heat, was assumed to be characteristic. Column (b) of TABLE II gives the shares of the CO_2-equivalent caused by the production and transport of the various components of the solar heating system.

Again the seasonal storage causes the largest contribution (52 % of 2 216 tons) followed by the solar collectors and the supports. The air-pollution effect by SO_2 is presented in column (c) of TABLE II.

3.2 Results for AEC and GWP during the operation of the solar heating system

During the utilization of the solar heating system, the only energy demand is electricity for the pumps. This electrical energy is transferred into primary energy assuming an efficiency (including electrical transport) of η= 0,33. The production of electricity also causes air pollution and a CO_2-equivalent.

In *Figure 2* the accumulated energy consumption and the generation of global warming gases are presented both for the period of production and the period of utilization of the solar heating system.

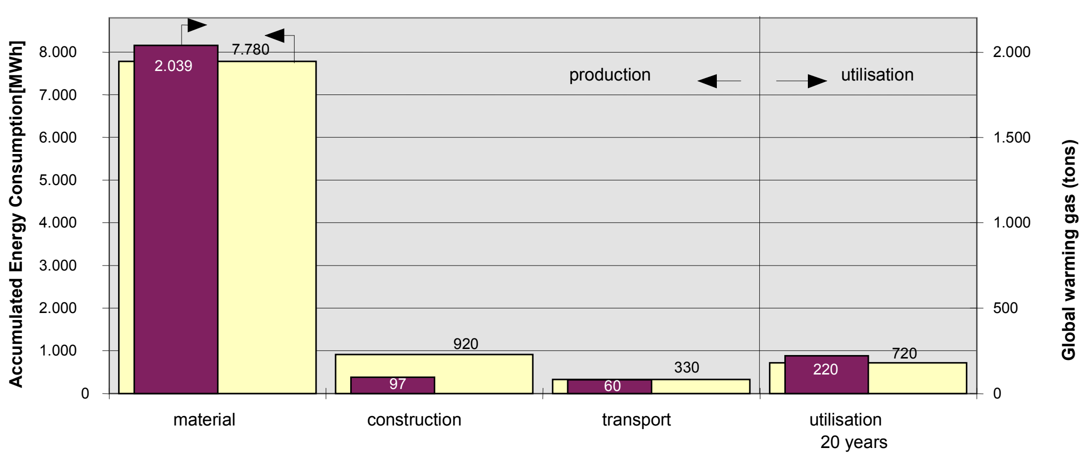

Figure 2. Accumulated energy consumption (AEC) and generation of global warming gases (GWP) for the solar heating system.

4. Energy Payback Time and Overall Energy Savings

The accumulated energy consumption for the period of production of the system and its utilization is shown in TABLE III. The annual energy savings by the solar heating system amount to 2 061 MWh and the annual operation AEC to 2 847 MWh. Considering a 20 years' utilization time, the AEC for pure gas heating amounts to 20x4 872 = 97 440 MWh.

The consumption for the solar assisted heating is in 20 years 20x2 847 = 56 940 MWh and with AEC for the production of 9 030 MWh the total AEC amounts to 65 970 MWh. So the savings in energy with the solar heating system are 31 470 MWh and the savings in GWP gases are 6 600 tons.

In *Figure 3* the energy payback time EPT is obtained as the point of intersection of the two straight lines representing the gas heating AEC and the solar assisted AEC.

The energy payback time is 4.5 years. There is a special interesting feature to the project under consideration. The project is being performed in two stages. In the first stage only 284 housing units were built and equipped with only 2 800 m^2 solar collectors. The hot water storage of 12 000 m^3, however, was built full size. Only this first stage is in operation. A second stage with again 284 housing units and another 2 800 m^2 will follow in 1999.

TABLE III. Accumulated Energy Consumption for the Solar Heating System.

	AEC (MWh)
Production of the system	9030
Annual AEC during utilization	
Gas heating only	4872
Gas heating combined with solar energy (42,3 % solar fraction)	2811
Pumping energy	36
AEC for gas and solar	2847

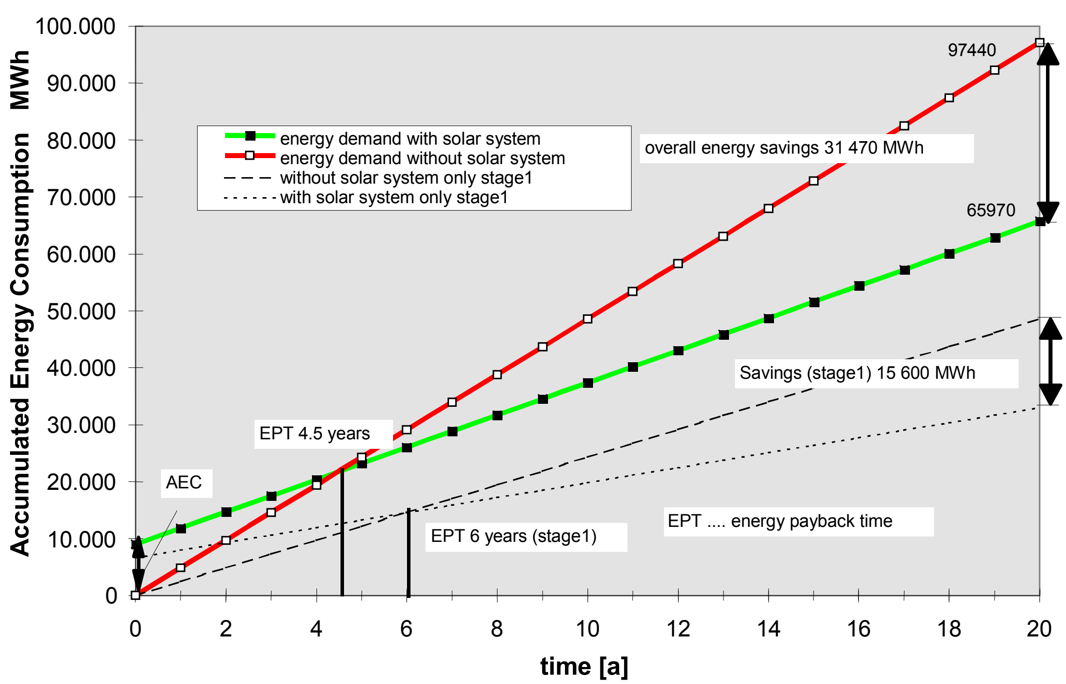

Figure 3. Accumulated energy consumption in 20 years of operation and energy payback time.

When the considerations which were made above for both stages would be applied only to the first stage, we would have an increase in solar gains per m^2 of collector area (small area and big storage). The specific energy demand, however, would also increase. In *Figure 3* it can be observed that the EPT increases from 4.5 to 6 years and the AEC-savings in 20 years amount to only 15 600 MWh for the first stage case.

5. Reductions in AEC and GWP

From TABLE II it is clear that the largest shares in the AEC and GWP are due to the seasonal storage and the collectors with their support structure. Reductions in AEC and GWP would most effectively start with these components.

5.1 Seasonal storage

Instead of the concrete pit used here other seasonal storage installations are conceivable, such as

- pebble/water storage with a plastic liner as sealing (built in Stuttgart at ITW and in Chemnitz)
- duct storage (built in Neckarsulm in a first stage)
- aquifer storage (planned in Berlin and Potsdam)

A comparison of the AEC and GWP for the construction of these stores is given in *Figure 4*.

The aquifer appears to be the best store from energy consumption and global warming gas production. But this is only half of the truth; the other is the energy consumption during operation. In *Figure 5* the overall savings in AEC and GWP are presented for a 20 years' period of operation. *Figure 5* demonstrates that the solar system with an aquifer storage yields only a saving of 27 206 MWh from 97 440 MWh for pure gas heating while the pebble/water storage exhibits the largest savings. Although the AEC for the construction of an aquifer is the smallest, the operation of such a store requires a large amount of electric pumping power and the store itself has a lower effectiveness than the others. The energetic payback time is consequently the least for the pebble/water storage with 3.2 years

5.2 Collector arrays

Solar collectors and their supporting structures together cause an AEC of the same amount as the concrete storage container. Possibilities for reduction could be

- integration of collectors into the roof (i.e. no supporting structure)
- use of recycled aluminium for the collector frame (reduces AEC from 60 kWh/kg$_{AL}$ to 33 kWh/kg$_{AL}$.

In *Figure 6* these possibilities are compared to the existing installation.

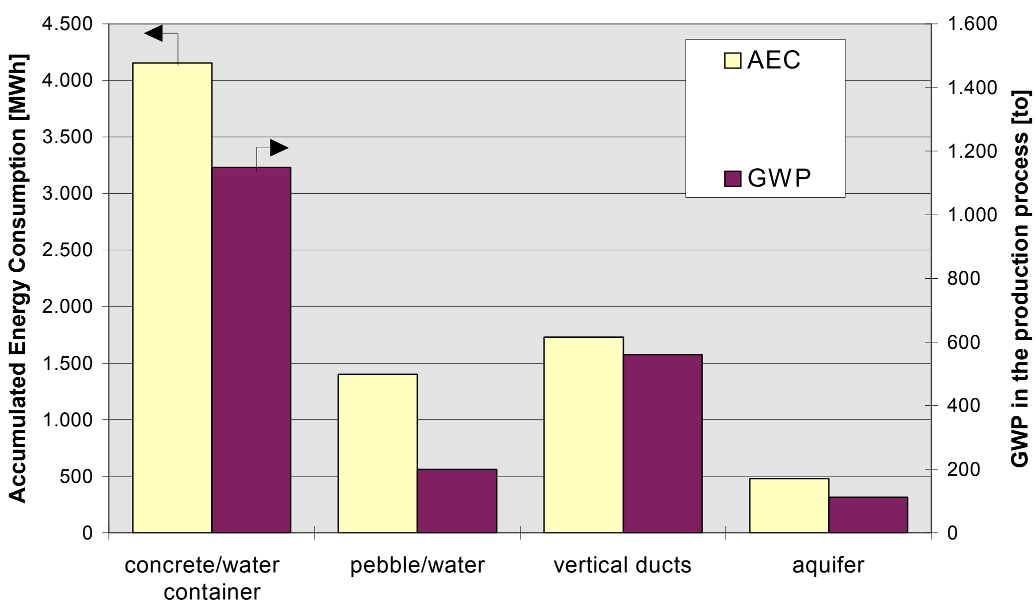

Figure 4. Comparison of AEC and GWP for the construction of different seasonal stores.

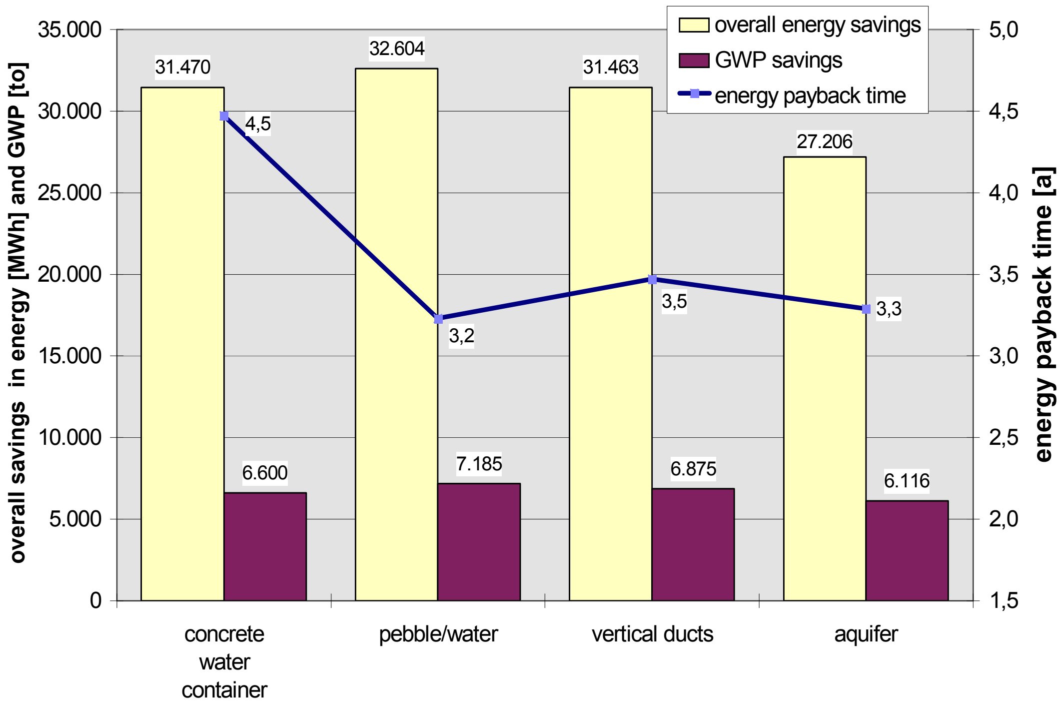

Figure 5. Overall savings in the AEC and GWP for a 20 years' period of operation and energy payback time (EPT) for different seasonal stores.

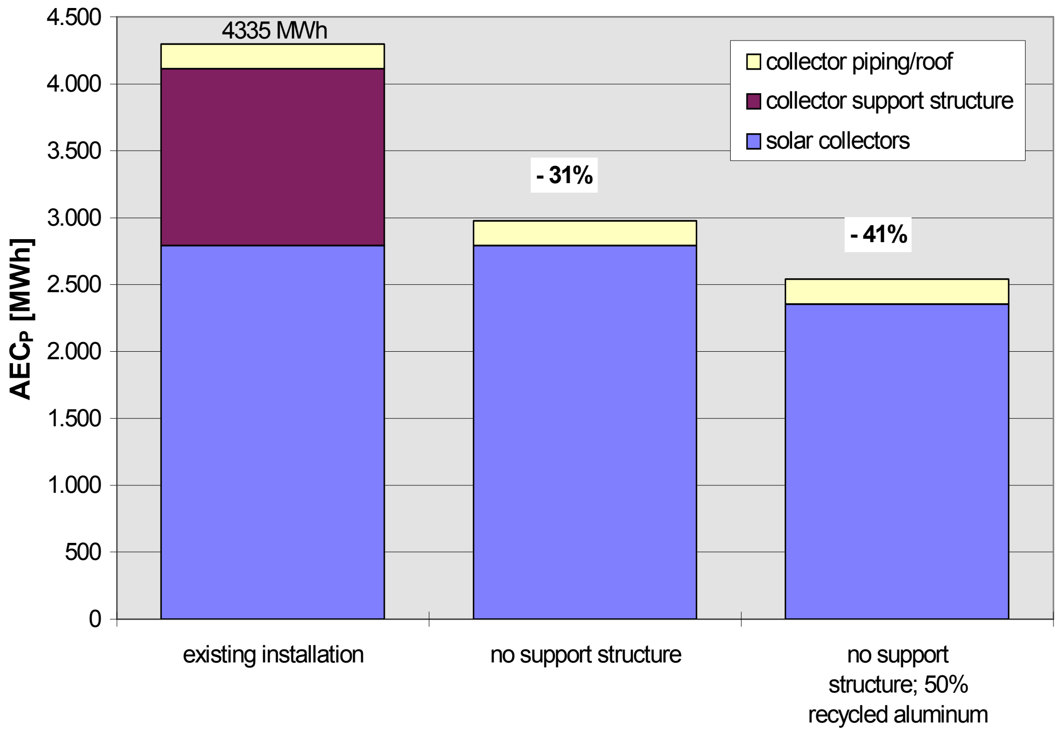

Figure 6. Comparison of AEC saving possibilities for the solar collector installation.

6. Conclusion

The comprehensive energy and emission balance gives insight into those processes and components which are most consumptive for energy and detrimental to atmosphere.

It allows for a better calculation of energetic payback time. Dismantling of the system - which is not included here - would of course bring forth an increase in all data obtained here, likely with about the same shares as calculated here. It is important to consider both production- and operational cost.

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