Solar Thermal Energy as a Topic in Secondary Mathematics Classrooms

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One of the most effective methods to achieve a sustainable change of our momentary existing power supply system to a system mainly based on renewable energy conversion is the education of our children. For this purpose the compulsory school subject mathematics appears to be suitable. In order to promote renewable energy issues in mathematics classrooms, the authors have developed a special didactical concept to open this field for students, as well as for their teachers. The aim of this paper is to present firstly an overview of our concept and secondly examples of problems to the special topic of solar thermal energy, developed on the basis of our concept.

1. Motivation

Especially the young generation would be more conflicted with the environmental consequences of the extensive usage of fossil fuels. The education of our children should bring up consciousness for the resulting problems. This would be one of the most effective methods to achieve a sustainable change of our momentary existing power supply system to a system mainly based on renewable energy conversion. Moreover, for our children it is indispensable to become familiar with renewable energies, because the decentralised character of this future kind of energy supply requires surely more personal effort of everyone.

In comparison to the parental education, the public schools give the possibility of a successful and especially easier controllable contribution to this theme. This can even be done advantageously for classroom teaching, as realistic and attractive contents have a particular motivating effect on students. In addition to that, a contribution to interdisciplinary teaching would be given, which is a significant educational method demanded by school curricula [1]. Regarding the fact, that not all students participate at technical orientated lessons in a comparable proportion, it seems to be especially suited to treat this topic in mathematics education for this purpose.

In addition this would be quite profitable for mathematics education itself, as “the application of mathematics in contexts which have relevance and interest is an important means of developing students' understanding and appreciation of the subject and of those contexts” [2, para F1.4]. Such contexts might be environmental issues, that are of general interest for everyone. Hudson [3] states that “it seems quite clear that the consideration of environmental issues is desirable, necessary and also very relevant to the motivation of effective learning in the mathematics classroom”. One of the most important environmental impacts is that of energy conversion systems.

However, although mathematics curricula demand application-oriented mathematics education, this not only in Germany [4, p.110], there is a great lack of mathematical problems suitable for school lessons [5, p.251]. Especially there is a need of mathematical problems concerning environmental issues that are strongly connected with future energy issues.[1] An added problem is, that the development of such mathematical problems affords the co-operation of experts in future energy matters with their specialist knowledge and mathematics educators with their pedagogical content knowledge. In such a co-operation the authors created several series of problems for the secondary mathematics classroom, based on a specially developed didactical concept.

2. Didactical concept

In order to promote renewable energy issues in mathematics classrooms, the authors have developed a special didactical concept to open this field for students, as well as for their teachers. The cornerstones of this didactical concept are:

- The problems are chosen that way, that the needed mathematical contents in order to solve them are part of mathematics school curricula.
- Advantageously every problem should concentrate on a special mathematical topic, such that it can be integrated in an existing teaching unit; as project-oriented problems referring to several mathematical topics are seldom picked up by teachers.
- The problems should not afford special knowledge of teachers concerning future energy issues and especially physical matters. For this reason all nonmathematical information and explanations concerning the problem's foundations are included in separated text frames.
- By going on this way information in respect to future energy issues is provided for both, teachers and students, helping them to concern themselves with the topic.

This didactical concept was first published by the authors at the '12. Internationales Sonnenforum 2000' in Freiburg [6]. On its basis, we have constructed and worked out several series of mathematical problems for secondary classrooms concerning the topics of rational usage of energy, photovoltaic, biomass, wind energy, thermal solar energy, traffic and transport; further problems for example to hydro power are in preparation.

We have presented our concept and problem examples in several conferences respectively teacher education events ([7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18]), with much positive reactions. The authors are grateful for the broad support they earned and the valuable hints and materials they received with regard to the development of further problems.

[1] One exception is H. Böer's working out of a project for mathematics lessons on the topic of parabolic sun collectors [24].

3. Examples for mathematical problems on solar thermal energy

This contribution provides in the following the short cuts of some examples of mathematical problems concerning future energy issues. The problems presented here deal with the topic 'Solar Thermal Energy'. They are suitable for lessons in secondary schools. Our presentation is focused on the basic structure of the problems, in order to give an impression of the didactical concept and the general principles.

3.1 Example 1

- This problem can be treated in lessons to the topic of percent calculation and the rule of three. It requires the understanding and usage of data representations.

Info:

In private households the required warm water can be partly heated up by solar thermal collectors. They convert the solar radiation energy in thermal energy. It helps us to decrease the usage of fossil fuels, which lead to environmental problems.

Hot process water needs preferably to have in private households about 45°-55°C. In our region, the usable thermal energy from the sun is not sufficient to reach this temperature permanently, because of the seasonal behaviour. Thus, an input of supplementary energy is necessary.

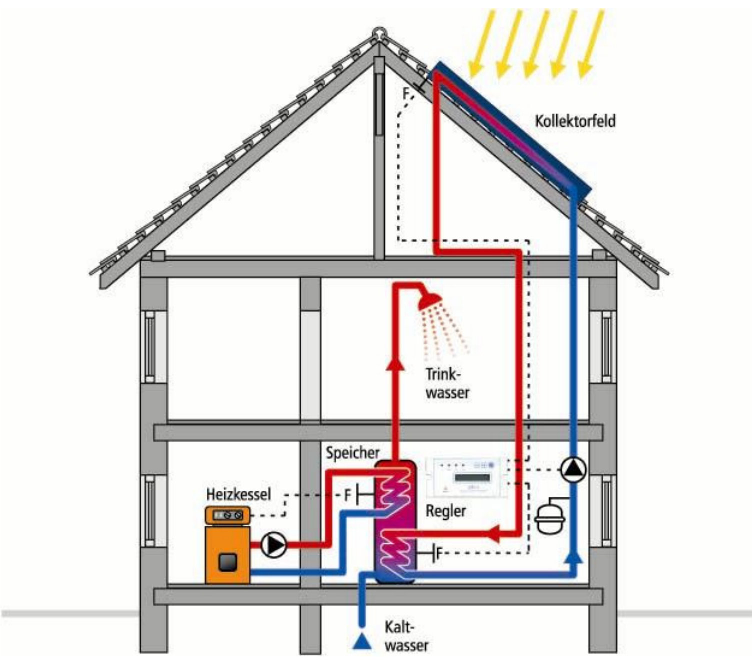

Figure 1: A solar thermal energy plant (DGS)

The following table shows how much of the needed energy for heating up water to a temperature of 45°C in private households can be covered by solar thermal energy, respectively how much supplementary energy is needed.

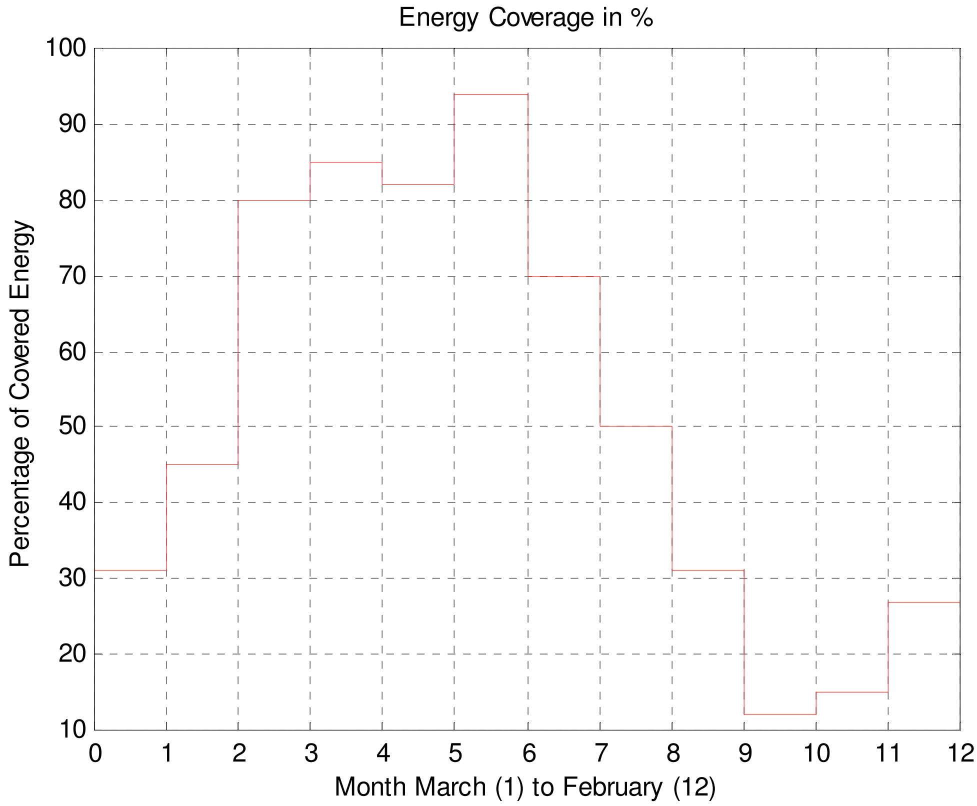

Figure 2: Usable Solar Energy and Additional Energy

a) How many percents of the needed thermal energy for one year can be covered by solar thermal energy?

Info:

Energy is measured by the unit kWh. An average household in Germany consumes nearly 16.000 kWh thermal energy per year. 1 l fossil oil provides approximately 10 kWh thermal energy. The combustion of 1 l oil produces nearly 68 l CO_2.

Assume in the following, that the used water is heated up to a temperature of 45°.

b) How many kWh may be covered in one year by solar thermal energy?

c) How many litres of oil have to be bought for the needed supplementary thermal energy for one year for a private household?

d) How many litres oil would be needed without solar thermal energy?

e) How many litres CO_2 could be saved by an average household in Germany during one year if using a Solar Collectors?

3.2 Example 2

- This problem deals with linear functions. The understanding and usage of graphical representations is performed.

Info:

Energy is measured by the unit kWh.

An average household in Germany consumes nearly 16.000 kWh thermal energy per year.

1 l fossil oil provides approximately 10 kWh thermal energy. The combustion of 1 l oil produces nearly 68 l CO_2.

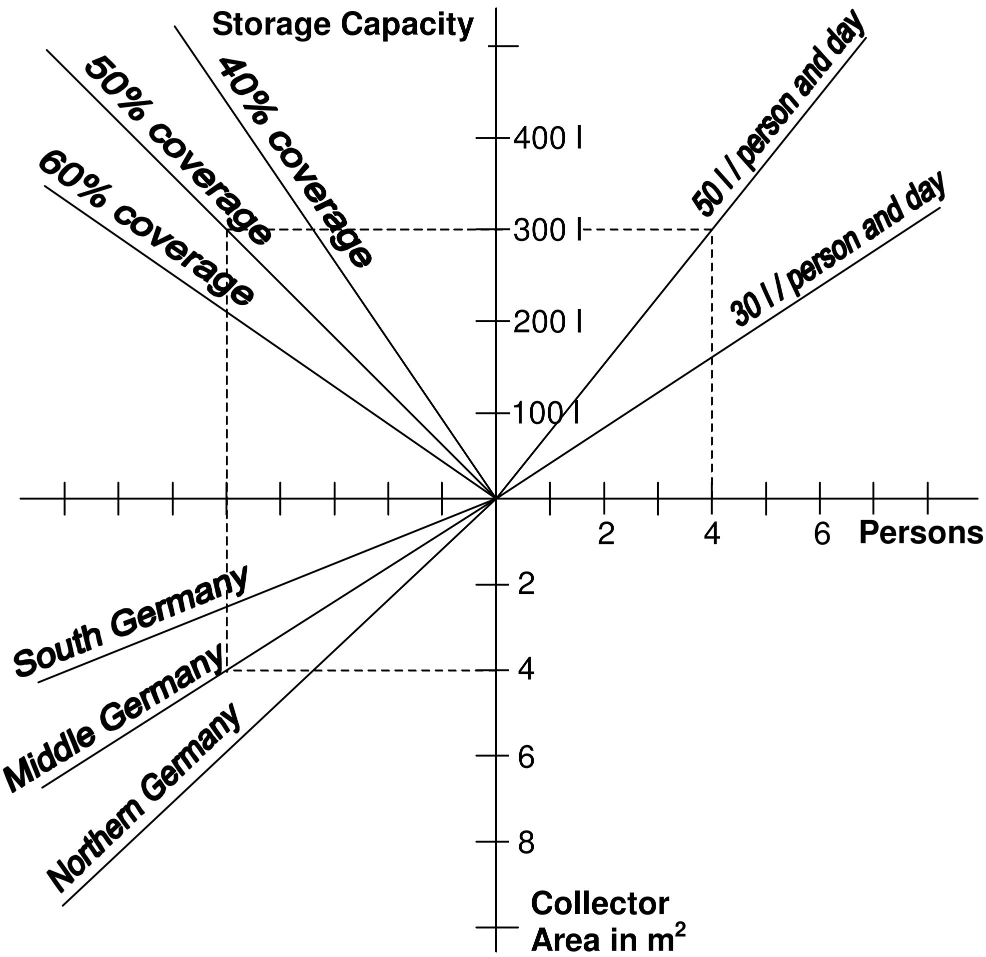

Figure 3: Dimensioning Diagram

The diagram in figure 3 provides data for planning a solar collector system for a private household. It shows the dependence of the needed collector area on the part of Germany where the house is situated, on the number of persons living in the respective household, on the desired amount of warm water per day and person, as well as the desired coverage of the needed thermal energy by solar thermal energy (in per cents).

Example: In a household in middle Germany with 4 persons and a consumption of 50 l warm water per day for each one, follows for a reservoir of 300 l and an energy coverage of 50%, that a collector area of 4 m^2 is needed.

a) What would be the needed collector area for the household you are living in? Which assumptions do you need to make first? What would be the minimal possible collector area, what the maximal one?

b) On a house in southern Germany there is installed a collector area of 6 m^2 that provides 50% of the produced thermal energy. How many persons could be supplied in this household with warm water?

c) Describe by the term of a linear function the dependence of the storage capacity on the number of persons in a private household. Assume first a consumption of 50 l warm water per day and person, and second a consumption of 30 l. Compare the two function terms regarding also their graphical representation.

d) Show in a graphical representation the dependence of the collector area on a chosen storage capacity, assuming a thermal energy coverage of 50% for a house in middle Germany.

3.3 Example 3

- This problem can be integrated in lessons to quadratic parabola and uses their focus property.[2]

Info:

Direct solar insolation may be concentrated in a focus by means of parabolic sun collectors. These use the focus property of quadratic parabola.

Special sun collectors are figures with rotation symmetry, they evolve by rotation of a quadratic parabola. Their inner surface is covered with a reflective mirror surface, that is why they are named parabolic mirrors.

Sun beams may be assumed as being parallel. Thus, if they fall on such a collector, parallel to its rotation axis, the beams are reflected that way, that they all cross the focus of the parabola. The thermal energy insolation may be focused this way in one point.

The temperature of a heating medium, which is lead through this point, becomes very high, relatively to the environment. This is used for heating purposes, but also for the production of electric energy.

[2] Similar problems may be found in [24].

Figure 4: Parabolic Sun Collectors (DLR)

a) A parabolic mirror was constructed by rotation of the parabola $y = \frac{1}{12}x^2$. Determine its focal length (x and y are measured in meter).

b) A parabolic mirror has a focal length of 10 m. Which quadratic parabola was used for its construction?

c) Has the parabolic mirror with $y = 0{,}05x^2$ a greater or a smaller focal length than that one in b)?

d) A parabolic mirror shall be constructed with a width of 2,40 m and a focal length of 1,25 m. How great is its arch, i.e. how much does the vertex lay deeper than the border?

e) In figure 5 you see a parabolic mirror, the EuroDish with a diameter of 8,5 m. Determine out of the figure approximately, neglecting errors resulting from projection sight, its focal length and the describing quadratic parabola.

Figure 5: EuroDish System (DLR Almeria Spain)

Info:

Other focussing sun collectors are figures with length-symmetry, they evolve by shifting a quadratic parabola along one axis direction. They are named parabolic trough solar collectors.

Figure 6: Parabolic Trough Solar Collectors

f) The underlying function of a parabolic trough solar collector is given by $y = 0{,}35x^2$ (1 unit $\hat{=}$ 1 m). Where has the heating pipe to be installed?

4. Final Remarks

The German version of all problems we developed in this project, including extensive explanations, and their solutions can be downloaded at the following internet address: http://www.math-edu.de under the topic ‘Anwendungen’.

The collection of worked out problems should finally be edited as a special text book for mathematics school education. For this purpose, the acceptance and supporting promotion of experts as well as politicians and educators is very important.

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