Solar Heating Systems for Houses
A DESIGN HANDBOOK FOR SOLAR COMBISYSTEMS
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Since the beginning of the 1980s, the rate of growth in the use of solar collectors for domestic hot water preparation has shown that solar heating systems are both mature and technically reliable. However, for several years, solar thermal systems seemed to be restricted to this application.

When the first systems for combined domestic hot water preparation and space heating, called solar combisystems, appeared on the market, complex and individually designed systems were the rule.

The combination of thermally well insulated buildings and low-temperature heat supply systems offered a wealth of new possibilities for solar space heating systems with short-term storage. In addition, the growing environmental awareness and subsidies in some countries supported an increase in the market share of this system type in many European countries.

From 1990 onwards the industry offered new, simpler and cheaper system technologies, but basic scientific knowledge was lacking in certain areas and on some methods. The designs were mainly the result of field experience and had not been carefully optimized. A first international survey in 1997 revealed more than 20 different designs that did not simply reflect local climate and practical conditions. Collaborative work in analysing and optimizing combisystems was seen as a proactive action that could favour high-quality systems that would be appropriate for a more global market. However, there were no common definitions of terms or standard test procedures for this type of system. This meant that it was difficult to determine a meaningful performance rating, and even more difficult to compare the systems.

While a great effort was made in Task 14 of the Solar Heating and Cooling Programme (SHC) of the International Energy Agency (IEA) — *Advanced Active Solar Energy Systems* — to assess and compare the performance of different designs of domestic hot water systems, in 1997 there was no available method for finding the ‘best’ solution for a combisystem in a given situation.

International co-operation was therefore needed to analyse and review more designs and ideas than one country alone could cover. It was felt that an IEA activity was the best way to deal with solar combisystems in a scientific and co-ordinated manner. Since it was also considered that combisystems needed further development in terms of performance and standardization, the IEA SHC launched Task 26 ‘Solar Combisystems’ in 1998.

From autumn 1998 to December 2002, 35 experts from nine European countries and the USA and from 16 solar industries worked together to further develop and
optimize solar combisystems for detached one-family houses, groups of one-family houses and multi-family houses. Furthermore, standardized classification and evaluation processes and design tools were developed for these systems. Another major outcome of Task 26 has been proposals for the international standardization of combisystem test procedures.

The further development and optimization of system technologies and designs by the Task 26 participants has resulted in innovative systems with better performance–cost ratings. The architectural integration of the collector arrays and the durability and reliability of solar combisystems were also investigated. This will lead to greater confidence amongst the end-users of this technology.

Both the solar industry and builders were involved in all activities in order to accelerate the dissemination of results on as broad a scale as possible.

This design handbook for solar combisystems summarizes the results of Task 26 and is also a contribution to the dissemination of the collaborative work. We hope that it will contribute to the large-scale use of solar energy for hot water and space heating.

The work on Task 26 and on the design handbook proceeded at a very high level thanks to the excellent co-operation of all the experts involved, for which I am very grateful. In particular, my heartfelt gratitude is extended to Jean-Chistophe Hadorn, who originally initiated the task, and to Jean-Marc Suter, Huib Visser and Wolfgang Streicher, who acted as the leaders of the three subtasks:

- Subtask A: Solar combisystems survey and dissemination of task results
- Subtask B: Development of performance test methods and numerical models for combisystems and their components
- Subtask C: Optimization of combisystems for the market.

I also very much appreciate the co-operation of all of the authors of this book, the help of Dagmar Jaehnig and Michaela Meir who assisted me in compiling and editing it, and the contributions of William A. Beckman, Chris Bales, Jill Gertzén and Jean-Marc Suter in proofreading.

Werner Weiss
Solar combisystems and the global energy challenge

Werner Weiss

The increase of greenhouse gases in the atmosphere, and the global warming and climatic change associated with it, represent one of the greatest environmental threats of our time and, in the future, also one of the greatest social dangers. The anthropogenic reasons for this impending change in the climate can for the greater part be put down to the use of energy and the combustion of fossil primary sources of energy, and the emission of CO\textsubscript{2} associated with this.

To set the course towards a sustainable energy future it is necessary to look for solutions that are based on renewable energy.

1.1 TOWARDS A SUSTAINABLE ENERGY FUTURE

Today, the world's energy supply is based on the non-renewable sources of energy: oil, coal, natural gas and uranium, which together cover about 82% of the global primary energy requirements. The remaining 18% is divided into approximately two thirds biomass and one third hydropower.

According to many experts, the effective protection of the climate for future generations will demand at least a 50% reduction in the worldwide anthropogenic emission of greenhouse gases in the next 50 to 100 years. With due consideration of common population growth scenarios and with the assumption of a simultaneity criterion for CO\textsubscript{2} emissions from fossil fuels, an average per capita reduction in the yield in industrial countries of approximately 90% will be required. This means a reduction to one tenth of the current per capita yield of CO\textsubscript{2} (Figure 1.1).

A reduction of CO\textsubscript{2} emissions on the scale presented will, however, demand conversion to a sustainable supply of energy, which is based on the use of renewable energy with a high proportion of direct solar energy use.

There is no doubt that it would be possible to supply technologically advanced countries exclusively with renewable sources of energy in the next 50 to 100 years. For example, the overall solar energy incident on the earth's surface exceeds by more than 10,000 times the world's current primary energy requirement.

There are numerous studies based on socio-economic, technological and institutional-structural models of global and national energy supply scenarios, showing shares of renewable sources of energy of 50% up to almost 100% in the next 50 to 100 years.

A reliable, favourably priced and environmentally sensitive supply of energy is an important prerequisite for the development of modern societies and for upholding and further improving the standard and the quality of life.
Beginning with the Final Report *Our Common Future* of the World Commission on Environment and Development (Brundtland Committee), which was published in 1987, and the Conference of the United Nations for the Environment and Development (UNCED), which took place in 1992 in Rio de Janeiro, the term *sustainable development* became a central idea in the 1990s and the overriding goal of global environmental and development policy.

Essential elements for the implementation of the concept of sustainable development in the field of energy are the orientation towards energy services, the efficient use of energy and the greater use of renewable energy sources, especially the direct or indirect use of solar energy.

The 'Brundtland Report' (1987) and the discussion about sustainable development, as well as the climate and environment conferences held in Kyoto (1997) and Johannesburg (2002), have resulted in most countries having developed programmes and mechanisms to implement renewable energies as part of the existing energy system and to extend their use. New legal and institutional frameworks have had to be, and still have to be, developed to reach the goals set. As well as the environmental concerns, factors such as security of supply and socio-economic development play an important role in most national programmes.

The European Commission has laid down its goals with respect to future development in the field of renewable sources of energy in the White Paper *Energy for the Future : Renewable Sources of Energy* (European Commission, 1997). In the Commission’s White Paper the following is mentioned as a strategic goal: ‘... to increase the market share of renewable sources of energy to 12% by the year 2010’. The yearly increase in the installed solar collector area in the Member States as given in the White Paper is estimated at 20%. Thus, solar heating systems in operation in the year 2010 would correspond to an overall installed collector area of 100 million m².
If the direct use of solar energy for heating purposes via solar collectors is to make a significant contribution to the energy supply in future, it is necessary that a variety of different types of systems are developed and established in the market, in addition to those supplying only domestic hot water. One very promising sector for solar thermal applications is space heating.

1.2 THE CONTRIBUTION OF SOLAR THERMAL ENERGY TO THE OVERALL HEAT DEMAND IN EUROPE

In 1998, energy consumption in the building sector totalled 16,077 PJ in European Union Member States, or around 40% of overall energy consumption in the European Union. Requirements for hot water and space heating amounted to 12,200 PJ, or 75%, of consumption in buildings. Of this, 9200 PJ was accounted for by residential buildings (Figures 1.2 and 1.3).

Since the heat needed in the building sector is low-temperature heat, this shows the large potential for solar thermal systems to provide space heating as well as domestic hot water for the inhabitants of the building.

1.2.1 Collector area in operation in the year 2000 in Europe

Since the beginning of the 1990s the European solar market has undergone considerable development. As the figures from the IEA Solar Heating and Cooling Programme (Weiss and Faninger, 2002) and the German Solar Energy Association (Stryi-Hipp, 2001) confirm, sales of flat-plate collectors recorded a yearly average
growth of 17% between 1994 and 2000. This meant that while 480,000 m² of collector area was installed across Europe during 1994, by 2000 the annual rate of installations was around 1.17 million m² of collector area, meaning that the rate had more than doubled within a period of six years.

The installed collector area in Europe was around 11.4 million m² at the end of 2000 (Table 1.1). Of this, 1.7 million m² was accounted for by unglazed collectors, which are used in the main to heat swimming pools, and 9.7 million m² by flat-plate and evacuated tube collectors used to prepare hot water and for space heating.

Table 1.1. Total collector area in operation in the year 2000 in EU countries (in m²)

<table>
<thead>
<tr>
<th>Country</th>
<th>Water collectors</th>
<th>Glazed</th>
<th>Evacuated tube</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>Unglazed</td>
<td>571,806</td>
<td>1,581,185</td>
<td>2,179,210</td>
</tr>
<tr>
<td>Belgium</td>
<td>21,875</td>
<td>19,400</td>
<td>1700</td>
<td>42,975</td>
</tr>
<tr>
<td>Denmark</td>
<td>15,563</td>
<td>243,169</td>
<td>100</td>
<td>258,732</td>
</tr>
<tr>
<td>Finland</td>
<td>10,200</td>
<td>10,200</td>
<td>100</td>
<td>10,300</td>
</tr>
<tr>
<td>France</td>
<td>84,500</td>
<td>470,000</td>
<td>554,500</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>615,000</td>
<td>2,399,000</td>
<td>392,000</td>
<td>3,406,000</td>
</tr>
<tr>
<td>Greece</td>
<td>2,815,000</td>
<td>2,815,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td>20,000</td>
<td>300,000</td>
<td>20,000</td>
<td>340,000</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>100,305</td>
<td>176,580</td>
<td>276,885</td>
<td></td>
</tr>
<tr>
<td>Norway</td>
<td>500</td>
<td>7000</td>
<td>7600</td>
<td></td>
</tr>
<tr>
<td>Portugal</td>
<td>1000</td>
<td>238,000</td>
<td>239,500</td>
<td></td>
</tr>
<tr>
<td>Spain</td>
<td>399,922</td>
<td>399,922</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweden</td>
<td>30,000</td>
<td>175,045</td>
<td>208,045</td>
<td></td>
</tr>
<tr>
<td>Switzerland</td>
<td>221,200</td>
<td>250,800</td>
<td>487,000</td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>149,000</td>
<td>149,000</td>
<td>151,000</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1,681,749</td>
<td>9,234,301</td>
<td>460,619</td>
<td>11,376,669</td>
</tr>
</tbody>
</table>

If the installed flat-plate and evacuated tube collectors up to the end of 2000 are considered, then Greece and Austria are in the lead with 264 m² and 198 m² respectively per 1000 inhabitants. They are followed by Denmark with 46 m² per 1000 inhabitants, Switzerland with 37 m² per 1000 inhabitants and Germany with 34 m² per 1000 inhabitants (Figure 1.4).

The markets that underwent the greatest growth in the time period mentioned above included Spain, the Netherlands and Germany. In the main, this can be attributed to the fact that the dissemination of solar heating systems had been very low in these countries, compared with Greece and Austria. In addition to this, deliberate state programmes of financial incentives contributed to high growth rates.

As mentioned above, in the White Paper on renewable energy, the European Commission set the goal of installing 100 million m² of collector area in European Union Member States. To achieve this ambitious goal, a yearly rate of increase of 38% is required up to 2010, meaning that the present growth rate would have to be a little more than doubled. Such a rate of increase can, however, only be reached if the Member States and the Union support this with corresponding measures for speedy market introduction and for research and development.
1.2.2 Current and medium-term energy supply from solar heating systems

Around 11.4 million m² of flat-plate and evacuated tube collectors were installed in Europe by the end of 2000. The calculated annual collector yield of all recorded systems in Europe is approx. 4600 GWh (17 PJ). This is annually saving the equivalent of 704 million litres of oil, thus avoiding the emission of 1.9 million tonnes of CO₂ into the atmosphere (Weiss and Faninger, 2002).

If it is assumed that the final energy consumption for hot water and space heating in the EU has not risen much since 1998, then around 0.14% of the overall requirements for hot water and space heating were covered by solar heating systems in 2000 across the EU. If the EC’s goal for 100 million m² of collectors by 2010 is met, then the total area installed will generate 144 PJ of heat per annum. If this is compared with the overall hot water and space heating requirements – for residential, commercial and public buildings – in 1998, then 1.18% could be covered by solar energy (Table 1.2).

Table 1.2. Current and medium-term energy supply from thermal collectors in Europe

<table>
<thead>
<tr>
<th></th>
<th>Energy (PJ)</th>
<th>Solar share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>12,171</td>
<td>0.14</td>
</tr>
<tr>
<td>Solar heat 2000 – EU</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Solar heat 2010 – EU</td>
<td>144</td>
<td>1.18</td>
</tr>
</tbody>
</table>

Developments in the building sector (low-energy and passive-energy houses) show that it is possible to reduce the specific heating requirements of new buildings...
quickly. As studies illustrate, existing buildings have medium-term potential for a reduction of 20% in the energy required for heating (European Commission, 2000). If such a reduction in heating requirements can be achieved in the medium term (i.e. up to 2010), then solar energy could provide around 2% of the energy needed by residential buildings for hot water and space heating in Europe.

At this point it should also be remembered that, until now, solar heating applications have concentrated almost entirely on the supply of hot water to single-family homes, whether individually or in small groups. In countries such as Germany, Switzerland and Austria, there has been a marked trend towards solar space heating systems for some years, and in this respect significant increases are anticipated in the years to come.

Results from Austria show that the targets for Europe are realistic and they illustrate the medium-term potential in a country where the solar heating market is already widely developed compared with other European countries.

If both the contribution solar energy currently makes to the supply of heat in Austria and its potential up to 2010 are analysed (Table 1.3), it becomes clear that, in the medium term, solar collectors will be able to supply significant amounts of thermal energy to meet heat requirements.

<table>
<thead>
<tr>
<th>Country</th>
<th>Requirements for hot water and space heating (1998)</th>
<th>Energy (PJ)</th>
<th>Solar share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td></td>
<td>303</td>
<td></td>
</tr>
<tr>
<td>Solar heat 2000</td>
<td></td>
<td>3.22</td>
<td>1.06</td>
</tr>
<tr>
<td>Solar heat 2010</td>
<td></td>
<td>12.87</td>
<td>4.25</td>
</tr>
</tbody>
</table>

Figures for Austria in 2000 indicate that the solar contribution to hot water and space heating requirements is 3.22 PJ or 1.06%; this means Austria has already reached the amount which all Member States of the EU are striving for in the medium term. If it is assumed that the average growth rates in Austria up to 2010 will be below the European average at 20%, because the market is already highly developed, then the collector area can be quadrupled in the next ten years. This corresponds to an overall collector area installed in Austria of approximately 8 million m². Thus in 2010, around 4.25% of the country’s overall hot water and space heating requirements can be covered by solar energy, provided that these requirements remain the same.

1.3 SOLAR COMBISYSTEMS – A PROMISING SOLUTION

The demand for solar heating systems for combined domestic hot water preparation and space heating, so called 'solar combisystems' is rapidly growing in several countries. In Sweden the share of the collector area installed for solar combisystems in 2001 was already significantly larger than the collector area installed for solar domestic hot water systems. In Austria, Switzerland, Denmark and Norway the collector area installed for solar combisystems and for solar domestic hot water
systems was almost the same. In Germany, which installed 900,000 m² of collector area in 2001, the share of the collector area installed for combisystems was 25%.

Figure 1.5 shows that in some countries, such as Germany, Austria, Switzerland, Sweden and Denmark, solar combisystems already have a noteworthy share of the market. The primary energy sources of these solar combisystems are solar energy with auxiliary sources such as biomass, gas, oil and electricity, either directly or with a heat pump.

![Figure 1.5. Share of collector area used for solar domestic hot water systems and for solar combisystems in selected countries](image)

A realistic approach would be to assume that, in the next ten years, a minimum of 20% of the collector area installed annually at middle and northern latitudes will be used for solar combisystems. This means that around 120,000 solar combisystems with 1.9 million m² of collectors need to be installed per year in the countries of the European Union, if the goals set in the European Commission’s White Paper are to be met (Figure 1.6). Increasing the installed collector area by a factor of 10

![Figure 1.6. Objectives for the installed collector area and market share of solar combisystems up to 2010 in the member countries of the European Union](image)
over 10 years is a major challenge, but this can be achieved if there is massive and continuous support, both political and financial, from the member countries.

Solar combisystems are more complex than solar domestic hot water systems, as there are more interactions with extra subsystems. The intrinsic complexity of implementing a solar combisystem working in conjunction with auxiliary heating has led to a large number of widely differing system designs. The most promising generic system designs are introduced in Chapter 4.

The solar contribution, which is the part of the heating demand met by solar energy, varies from 10% for some systems to up to 100% for others, depending on the size of the solar collector, the storage volume, the hot water consumption, the heat load of the building and the climate.

The different system concepts can partly be attributed to the different conditions prevailing in the individual countries. Thus, for example, the 'smallest systems' in terms of collector area and storage volume are located in those countries in which gas or electrical energy are primarily used as auxiliary energy. In the Netherlands, for example, a typical solar combisystem consists of 4–6 m² of solar collector and a 300 litre storage tank. The share of the heating demand met by solar energy is, therefore, correspondingly small.

In countries such as Switzerland, Austria and Sweden, where solar combisystems are typically coupled with an oil or biomass boiler, larger systems with high fractional energy savings (the term is defined in the appendix) are encountered. A typical system for a single-family house in these countries consists of up to 15–30 m² of collector area and 1–3 m³ of storage tank volume (Figure 1.8). The share of the heating demand met by solar energy is between 20% and 60%. In some cases of extremely well insulated houses and low-flow mechanical ventilation, the solar contribution can even reach 100%.

Apart from collector types and storage tank details, the layout of the system, that is the connections between components, is one of the most differentiating items among the various system concepts analysed in Task 26. Based on the experience of Task experts, the requirements for the hydraulic layout of solar combisystems can be summarized as follows (Streicher, 2000):

Figure 1.7. A Dutch house with a solar combisystem (Source: ATAG, The Netherlands)
Figure 1.8. Solar combisystem for a single-family house in Sweden (Source: K. Lorenz, SERC, Sweden)

- the delivery of solar energy to heat store(s) and heat consumers with as low a heat loss as possible
- the production and delivery of auxiliary heat to consumers with as low a heat loss as possible
- the distribution of all the heat needed to meet hot water and space heating demands
- the reservation of sufficient storage volume for auxiliary heating, with the minimum running time for the specific heater taken into account
- low investment costs
- low space demand
- easy and fail-safe installation
- reliable operation and low maintenance cost.

These conditions require simple systems in terms of connections, compared to the systems designed and constructed in the 1980s.

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SIMULATION PROGRAMS

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9 Built examples

10 Testing and certification of solar combisystems


Drück H, 2000, MULTIPORT store model for TRNSYS, Type 140, Version 1.99, Institut für Thermodynamik und Wärmetechnik (ITW), Universität Stuttgart, Stuttgart, Germany.


E N 45000/17000: Series of standards on conformity assessment and accreditation of laboratories


characterization by means of whole-system tests and computer simulation

ISO 9000, Series of standards on quality management and quality assurance


The European standards are available from the national standardization bodies.
Appendix 2: Vocabulary


ISO 9488:1999 Solar energy - Vocabulary/Energie solaire - Vocabulaire. International standard/Norme internationale, ISO, Geneva, 1999. This is a trilingual standard also including terms and definitions in German, which has been adopted as the European standard EN ISO 9488.

Available from the national standardization institutes.

Primary energy consumption of electrical heating.

El. heater Q, let. heater

\[ E = E + E \]

total mix par
\[ E_{\text{tot}} = E_{\text{til}} + E_{\text{nj ref par,rcj}} \]