On-site evaluations of three solar thermal heating system concepts were carried out. These are the compact combisystem unit with gas auxiliary heater (REBUS-gas), the unit with pellets auxiliary heater (REBUS-pellet) and the integrated collector storage system ICS (Solior). The measurements followed the theoretical system evaluation which was also part of NEGST (/NEGST/). The theoretical evaluation of promising system concepts is described in /Vog06/, which also contains a description of each of the systems. Besides these three system concepts which were field-evaluated in detail with measurements, other systems evaluated theoretically were very successful on the market before the end of the project. Two of these systems are the Compact heating unit for solar domestic hot water (SDHW) preparation (auroCOMPACT) and the solar heating system concept with water filled collector loop (AquaSystem). Thanks to the large number of installed systems, many experiences could be gained.

This report summarizes the results of the field measurements taken on the three system concepts evaluated scientifically. Also it includes some of the experiences gained from the system types installed in large numbers and directs the reader to two separate reports where the experiences are described in more detail.

This following section SELECTED RESULTS presents highlights of the evaluation. The complete information can be found in the documents mentioned below and listed in the section REFERENCES. As a general result it can be stated that:

- The system performance often exceeded the expectations.
- Secondary benefits turned out to be important (e.g.: the marketing of the system concept with water filled collector loop was particularly successful because the concept turned out to be well suited for retrofit installations; the reduction of circulation heat losses, enabled by the controller of the REBUS-gas system, contributed significantly to the gas savings observed in the demonstration house during the on-site evaluation).

The main authors of the most important sections of this report are: Alexander Thür (reporting on REBUS-gas); Chris Bales (REBUS-pellet); Anton Schaap (ICS, Solior).
SELECTED RESULTS

Combisystem unit with integrated gas auxiliary heater (REBUS-gas)

Boundary conditions for a Danish/Swedish solar combisystem

The Danish energy sources for heating residential buildings are mainly based on natural gas or district heating. This is why a concept of a solar combisystem in combination with a condensing natural gas boiler was developed in Denmark in close cooperation with the Danish main industry partner, Metro Therm A/S (/Thü06/, /Thü07/, /Fur07/). In Sweden, pellet heating is a common auxiliary heater in solar combisystems. In addition there are many electrically heated houses of which the space heating system will be converted to other energy sources in the next few years due to governmental incentive mechanisms. The REBUS concept shall be suited for both markets. Further main boundary conditions specific for the situation in Denmark are:

- Till now, in Denmark solar combisystems are relatively small. Typical design figures are 8 m² collector area and up to 300 litre domestic hot water storage volume, where the collector loop is directly connected to the space heating loop via a plate heat exchanger. This system design does not allow storage of solar heat in a water tank for space heating purposes, therefore the solar fraction is very low. In the last years, larger systems using several types of tank in tank concepts are used. Also due to the rising energy prices it is expected that the demand of competitive, advanced and compact solar combisystems is getting larger in future.

- One-family houses in Denmark typically have no basement. Therefore, also no technical rooms exist where a lot of space is available to install the heating system. Due to this fact, heating systems are more or less integrated in the living area, which means that they are situated e.g. in the entrance room, the bathroom, the kitchen or a store room. Because the heating system is optically present in the living area, it is a strong need to have a nice design and to have all the pipes and other components hidden behind an optically nice façade. Also the space requirement for the installation should be minimized.

- Since, due to the small market, the experience of installers in solar heating technology is typically rather low, a high degree of prefabrication of the solar combisystem is the best solution to avoid installation mistakes. Prefabrication typically also reduces the installation cost and increases the efficiency of the whole system.

- The system design shall be flexible in order to be able to integrate boilers from different producers and different types of boiler (e.g. natural gas-, oil-, pellet boiler) as well. The system concept should also be easily usable for different system size which means solar heating systems with low to high solar fraction. A main focus shall be to develop a system concept including an advanced control algorithm which leads to best possible operating conditions for both the condensing natural gas boiler and the solar collector in order to get the highest possible overall system performance.

Description of the system

Based on the boundary conditions described above, the following system concept was developed, which is shown in figure 1. The solar combisystem consists of two main units, the solar store unit and the technical unit.

The solar store unit is integrated in a compact and nice looking cabinet with a ground area of 60 x 60 cm, as long as the volume is less than about 400 litres. For larger volumes, several such units can be connected in series and placed side by side. For reduced heat losses also a large single tank can be used which allows a hydraulic connection to the technical unit as it is needed according to the system concept (see also figure 2).

The technical unit includes the controller and all hydraulic components (pumps, valves, expansion vessel, heat exchangers, etc.) which are needed to collect energy from the heat sources (boiler and solar collector) and to distribute it in the most efficient way directly to the demand (space heating loop or domestic hot water preparation) or to store the energy with a minimum of exergy losses according to the temperature level of the energy input and the actual stratification in the tank. This technical unit can be delivered to the installation site totally
prefabricated, also with the condensing natural gas boiler inside. Then the remaining installation work which needs to be done is only to connect the pipes between the technical unit and the solar store unit and between the technical unit and the piping in the house (space heating, domestic hot water, solar loop, natural gas and exhaust pipe) plus some small electrical work.

Fig. 1: The compact solar combisystem as two units with 60 x 60 cm ground area: On the left side a solar tank and on the right side the prefabricated technical unit in which the condensing natural gas boiler, the controller and all the other components like pumps, switching valves, mixing valves, expansion vessels, plate heat exchanger, etc. are located.

Fig. 2: Hydraulic scheme of the solar combisystem.
Due to the modular approach and the fact that the technical unit contains all parts necessary for a complete heating system, it can be sold on its own. It is then completely prepared for solar, which can be added at a later stage by installing the collector and connecting it to the technical unit and hydraulically connecting the technical unit to the solar store by 5 pipes. The main criteria when developing this system concept was to optimize the operating conditions for the two energy sources solar collector and condensing natural gas boiler. For high efficiency, both need lowest possible return temperatures. Unfortunately most of the condensing natural gas boilers have integrated bypass valves, which are raising the return flow temperature if the flow rate is lower than the allowed minimum flow rate. Typically, this minimum flow rate is between 450 and 600 litres per hour. But a radiator space heating system is operating with flow rates mostly between 100 and 400 litres. To make these different flow rates fit together, a buffer volume is needed.

In combination with condensing natural gas boilers, which have sufficient high peak power (about 30 kW) for direct hot water preparation an advanced control concept can be used. The main difference of this concept is to use the auxiliary volume as a buffer, but NOT to keep the auxiliary volume at a high set temperature (typically 60-70°C) for domestic hot water preparation. This is possible because the boiler is powerful enough to cover the domestic hot water demand directly. Therefore, the boiler is always operating at lowest possible forward temperature including the possibility to use the auxiliary volume as a buffer. The advantage resulting from this approach is due to several effects:

- Especially in wintertime, the average tank temperature in the top part is comparable low and therefore, also the heat loss of the tank is lower.
- Since the average tank temperature in the top part is lower, this in fact is enlarging the heat capacity, which can be used by the solar collector to gain and store more solar energy into the same tank volume. Especially in small tanks (e.g. 90 litres auxiliary volume as part of a 300 litre tank) this can lead up to about 20% more effective useful heat capacity.
- The average temperatures in the pipes connecting boiler and tank are lower and therefore again the heat losses are lower. This is also true for the hot forward flow pipe between the tank and the mixing valve.
- Due to the lower temperature level the boiler in average is operated, higher condensation rates of a condensing natural gas boiler can be expected which is increasing the boiler efficiency.
- Using an auxiliary buffer volume also is dramatically reducing the start/stop frequency of the boiler. This has positive effects on the reliability of the boiler components and the flue gas quality. Furthermore it leads to reduced emissions.

Furthermore, an advanced control strategy for the domestic hot water circulation pump was integrated, the so called “circulation on demand”. The circulation pump is not running all the time but switched (triggered) on when hot water is tapped. The pump continues to run for some time afterwards. Once the hot water circulation is activated, it takes about 20 seconds (in the demonstration house, which is described later) until hot water is available at the tap without continued tapping. If people are adapted to this system the short waiting time may be used for other activities and its disadvantage is small compared to the huge amount of energy saved.

**Description of the demonstration house**

The demonstration house used for the REBUS-gas system is situated in the small town Helsinge, about 40 km north of Copenhagen (56°01’ N, 012°12’ E) and occupied by two adults and one teenager. The house shown in figure 3 has three floors: the basement with an entrance room, a bedroom, a bathroom and the technical room, the first floor with kitchen, living room and dining room and the second floor with two bedrooms and a bathroom. The house is about 9 m in length (east-west) and 7 m in width. Therefore, the gross area in the basement and the first floor is about 63 m² and in the second floor 46 m² which results in a total area of about 172 m².

The space heating distribution system mainly consists of several old cast iron radiators. The bed in the basement has floor heating with an extra pump with integrated mixing valve, which is controlled by a room temperature sensor. The other floor heating loops, each with a return temperature control thermostat valve, are in the entrance room and in the bathroom in the
basement as well as in the bathroom in the second floor. These floor heating loops are supplied with the same forward temperature as the radiators.

The old heating system in this demonstration house was supplied with heat by a non-condensing natural gas boiler. For domestic hot water preparation the natural gas boiler heated a hot water tank:

- Natural gas boiler: Vaillant, nominal power: 22 kW; construction year: 1990
- Domestic hot water tank volume: 50 litres
- Number of pumps: 3; The main pump was integrated in the gas boiler, one extra pump for the floor heating in the bedroom in the basement and one hot water circulation pump.

![Image: View on the demonstration house from the south (left) and the installed REBUS-gas solar heating system in the basement (right).](image)

The new solar combisystem was equipped with the following components:
- Collector: VELUX, 5 pieces of type: S08 (D2178)
- Collector area: 6.75 m² (aperture area)
- Tilt angle of the roof: 45°
- Azimuth of the roof: 15° East
- Condensing natural gas boiler:
  - Distributor: Milton A/S
  - Type: Milton Smart Line HR24
  - Nominal power, space heating: 5.7 – 23.0 kW
  - Nominal power, hot water: 5.7 – 28.5 kW
- Solar tank:
  - Total volume: 360 litres
  - Auxiliary volume: 90 litres

In order to have an as large as possible tank volume within the 60 x 60 cm cabinet a new tank was designed and produced as a prototype for this demonstration system. Standard tanks of Metro Therm A/S, which fit into a 60 x 60 cm cabinet, have a diameter of 500 mm. This prototype tank has a diameter of 550 mm and also fits into the 60 x 60 cm cabinet. Due to the 10% larger diameter, the volume of the tank increased by about 20%. In order to keep the heat loss in the same range, on the four sides, where the insulation thickness would be only 25 mm, vacuum panels with a thickness of 20 mm were embedded into the foam. Measurements at SERC (Solar Energy Research Center) in Sweden resulted in a heat loss coefficient of about 2 W/K (see figure 4).
Fig. 4: Heat loss rate of the REBUS solar storage measured at SERC (red diamond), compared to test results of other solar stores as measured at ITW, University of Stuttgart (black diamonds).

Monitoring results

In order to show an overview on the typical natural gas consumption the house owner was asked for the yearly natural gas consumption in the last years. For the following accounting periods the natural gas consumption and the heating degree days were:

- 6/5-2001 till 5/5-2002: 2,524 m³ (26,931 kWh) 2973 Kd
- 5/5-2002 till 28/4-2003: 2,693 m³ (28,734 kWh) 3243 Kd
- 28/4-2003 till 10/5-2004: 2,927 m³ (31,231 kWh) 3090 Kd
- 1/1-2005 till 31/12-2005: 2,355 m³ (25,131 kWh) 3097 Kd

Space heating demand: 17,974 kWh; Domestic hot water consumption: 3,279 kWh (9.0 kWh/d)

Detailed monitoring in the demonstration house was done from January 2005 until May 2007. In May and June 2006 the old heating system was replaced by the new solar combsystem. In this period domestic hot water was prepared by a small electric powered domestic hot water heater. From July until September 2006 for the new solar combsystem only the natural gas consumption could be measured. In October 2006 detailed monitoring with several energy meters was started.

The measured natural gas consumption for the old conventional heating system (Old) and the new solar combsystem (SCS) for equivalent summer and winter periods are:

- Summer consumption 7/07-05 – 30/9-06 (85 days) Old: 1,509 kWh
- Summer consumption 7/07-05 – 30/9-07 (85 days) SCS: 318 kWh
- Winter consumption 1/10-05 – 30/4-06 (212 days) Old: 24,435 kWh (2982 Kd)
- Winter consumption 1/10-06 – 30/4-07 (212 days) SCS: 14,719 kWh (2232 Kd)

For the winter period it must be considered that, on the one hand, the heating degree days of the winter 2006/07 were about 25% lower compared to the winter before. On the other hand, since summer 2006 the basement in this house is used as living area and therefore heated as well. Furthermore since October 2006 the thermostatic valves were used correctly following instruction of the users. Before that time the thermostatic valves were used as simple on/off valves.

In figure 5 and table 1 the monitoring results of the new solar combsystem for the period October 2006 until May 2007 are presented:
The conditions (heating degree days, additional use of the basement, different operation of the thermostatic valves of the radiators, etc.) which occurred in the periods before and after the installation of the REBUS combisystem varied considerably. In order to be able to compare the old heating system and the new solar combisystem a coefficient of performance (COP) was defined. The COP is the domestic hot water plus space heating loads divided by the natural gas consumption. Figure 6 shows the COP for both the new and the old heating systems. In the case of the old heating system there is a clear dependency of the COP from the heat load. This dependency is not clear in the case of the new system because of the important contribution of solar energy. Also, a hydraulic efficiency was defined. It is the energy output from the heating unit (domestic hot water and space heating) divided by the heat input to the unit (solar and boiler). These definitions imply that the heat used for domestic hot water circulation is considered lost rather than utilized, which explains the remark “Circulation as Loss” in the columns “COP” and “eta hyd” of table 1.

Table 1: Energy data of the new installed solar combisystem:

<table>
<thead>
<tr>
<th>Ambient Temperature Average</th>
<th>Solar Gain [kWh]</th>
<th>Natural Gas Consumption [kWh]</th>
<th>Space Heating [kWh]</th>
<th>Domestic Hot Water-Consumption [kWh]</th>
<th>Domestic Hot Water-Circulation [kWh]</th>
<th>Electricity Consumption [kWh]</th>
<th>Boiler Efficiency [%]</th>
<th>Domestic Hot Water-Consumption (DHW+SH)/(Gas<em>eta_boil)</em></th>
<th>Domestic Hot Water-Circulation as Loss</th>
<th>Space Heating as Loss</th>
<th>(Solar)/(Solar+Boiler)</th>
<th>COP</th>
<th>SF</th>
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<td>[kWh]</td>
<td>[kWh]</td>
<td>[kWh]</td>
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<td>15.8</td>
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<td>75.5</td>
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<td>91.4%</td>
<td>134.9%</td>
<td>40.5%</td>
<td>87.8%</td>
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</tr>
</tbody>
</table>

The conditions (heating degree days, additional use of the basement, different operation of the thermostatic valves of the radiators, etc.) which occurred in the periods before and after the installation of the REBUS combisystem varied considerably. In order to be able to compare the old heating system and the new solar combisystem a coefficient of performance (COP) was defined. The COP is the domestic hot water plus space heating loads divided by the natural gas consumption. Figure 6 shows the COP for both the new and the old heating systems. In the case of the old heating system there is a clear dependency of the COP from the heat load. This dependency is not clear in the case of the new system because of the important contribution of solar energy. Also, a hydraulic efficiency was defined. It is the energy output from the heating unit (domestic hot water and space heating) divided by the heat input to the unit (solar and boiler). These definitions imply that the heat used for domestic hot water circulation is considered lost rather than utilized, which explains the remark “Circulation as Loss” in the columns “COP” and “eta hyd” of table 1.
Fig. 6: Comparison of the coefficient of performance (COP) of the old heating system and the new solar combisystem.

With the dependency of the coefficient of performance (COP) from the total monthly heat load the natural gas consumption of the old heating system can be estimated for the period when the new REBUS system was in operation. Figure 7 and table 2 show the gas consumption of the old and the new system. Also the energy savings resulting from these figures are presented. 2482 kWh gas was saved during the 8 months period. The specific energy savings (per collector area) were 368 kWh/m². The specific solar gain of the same period amounted to 217 kWh per square metre collector area.

Fig. 7: Monthly energy consumption and energy savings of the new solar combisystem (SCS) compared to the old heating system.
Table 2: Energy savings of the new solar combisystem compared to the old heating system:

<table>
<thead>
<tr>
<th>Month</th>
<th>Heat Load (SH+DHW)</th>
<th>COP old [%]</th>
<th>COP SCS [%]</th>
<th>Natural Gas Consumption old [kWh]</th>
<th>Natural Gas Consumption SCS [kWh]</th>
<th>Energy Savings [kWh]</th>
<th>Energy Savings [kWh/m²]</th>
<th>Solar Gain [kWh/m²]</th>
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</table>

Total 15313 86,1 100,1 17776 15294 2482 368 217

In the months October 2006 to February 2007 the energy savings can be explained mainly by the higher efficiency of the condensing natural gas boiler compared to the old non condensing natural gas boiler (see also table 4). Detailed investigations showed that the boiler efficiency during this period is higher than expected (in comparison to typical installations). This improvement is due to the advantageous hydraulic integration inherent with the new system. During the 3 months March, April and May 2007 the solar collectors contributed significantly to the heating system, resulting in COP values clearly above 100%.

In table 3 estimated figures for the complete year are presented. It is expected that the new solar combisystem (6.75 m² collector area and 360 litre solar tank) will lead to energy savings of about 3750 kWh (20%). The specific savings (per square metre of collector area) are about 555 kWh/m². The specific collector gain is expected to be about 433 kWh/m².

Table 3: Estimated energy savings of the new solar combisystem (SCS) compared to the old heating system for one year (for June till September 2007 estimated values were used):

<table>
<thead>
<tr>
<th>Month</th>
<th>Heat Load (SH+DHW)</th>
<th>COP old [%]</th>
<th>COP SCS [%]</th>
<th>Natural Gas Consumption old [kWh]</th>
<th>Natural Gas Consumption SCS [kWh]</th>
<th>Energy Savings [kWh]</th>
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<td>04.2007</td>
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Total 16453 84,1 104,0 19568 15819 3749 555 433

Table 4 shows an overview of the main monitoring data of the old heating system (January 2005 till April 2006) and the new solar combisystem (October 2006 till May 2007).

NEGST – NEW GENERATION OF SOLAR THERMAL SYSTEMS
is a project financed by the European Commission DGTREN within FP6
Table 4: Overview of the main monitoring data of the old heating system and the new solar combisystem:

<table>
<thead>
<tr>
<th>Date</th>
<th>Ta (°C)</th>
<th>Gas [kWh]</th>
<th>Solar [kWh]</th>
<th>DHW [kWh/d]</th>
<th>Circ. [%]</th>
<th>Elec. [%]</th>
<th>sta. boil [%]</th>
<th>COF</th>
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<td>3.2</td>
<td>98.6</td>
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Conclusions:

- Major improvements could be achieved by significantly reducing the domestic hot water energy consumption of about 20%, mainly due to a reduced hot water set temperature of 50°C instead of almost 70°C before. This smaller temperature reduced quite strongly the heat losses of the pipes due to a 40% lower temperature difference (50/20 instead of 70/20).
- The efficient concept of “circulation on demand” could be demonstrated very successfully. The hot water circulation losses of the newly installed solar combisystem are less than 10% relative to the whole domestic hot water consumption. In several studies circulation heat losses of 50 to 100% are reported as typical values. Also, in this demonstration house the circulation losses from November 21st till December 21st, 2005 were in total 297 kWh representing almost exactly 100% of the domestic hot water consumption which was at that time period 292 and 295 kWh respectively.
- The electricity consumption in the new solar combisystem during the heating period was about 5% lower compared to the old heating system even though that in total 3 pumps more were installed. A major reduction could be realized by the possibility to adapt the space heating pump speed to the real demand using the integrated pump speed controller.
- The hydraulic efficiency of the new solar combisystem could be demonstrated to be comparable very high. Despite the fact that the solar storage tank has an about 7 times larger volume (360 litres of the solar storage tank compared to 50 litres of the domestic hot water tank of the old system) and the effort of piping and the number of components is naturally somewhat higher, the hydraulic efficiency of 90 to 95% during the core heating season is a quite high value if compared to results from other field measurements (/Woł04/).

More detailed information on the system and its on-site evaluation is available in /Fur07/ which covers both the compact heating unit (REBUS) with gas and pellets auxiliary heater.
Combisystem unit with integrated pellets auxiliary heater (REBUS-pellet)

Demonstration Site
Initial field testing of the compact solar heating unit with a pellets auxiliary heater (/Fie05/, /Fie07/) was carried out on one installed system. A number of different potential sites for the demonstration system were checked to select a well suited test site. The house was built around 1910 and has been refurbished a couple of times since then. Until the beginning of 2006 the house was heated by electric heater panels and for domestic hot water preparation an electrically heated store was used. The owner was very interested in converting to a pellets and solar heating system due to the high heating costs with electricity. The house is quite typical for houses of that age. There are approximately 40,000 houses of this house type of the roughly 500,000 electrically heated houses in Sweden in total. There is also a garage/workshop on the property that is also heated electrically. Before the installation of the REBUS solar thermal system, approx. 23,000 kWh/a electricity was used in the main house and the garage/workshop as well as small amounts of log wood for heating in the main house.

Installation
During the spring of 2006 a number of water based radiators were installed in the main house and the electrical panel heaters were removed. The panel heaters have been kept in the garage, although it is planned to make a culvert to the garage and supply heat from the REBUS system at a later date. The REBUS system was installed in the middle of July 2006 without the pellet stove because of technical problems with the chimney. The stove was installed in the middle of October 2006. Up until this date a 6 kW electrical heater in the 80 litre standby store in the technical unit was used as auxiliary heater. The pellets stove is situated in the middle of the living room and is fed manually by the owners (see figure 9, below, middle). The technical and store units were installed in a small room/cupboard under the stairs requiring the technical unit to be lower than standard height (see figure 10, right). To match these requirements, it was possible with the chosen system variant with separate pellet stove. The collector field of 10 m² (figure 8, left) consists of four modules of Svesol premium AR with a standard rated output of 465 kWh/a for Stockholm weather conditions at a constant temperature of 50°C. The collector was placed on the main roof facing 40°E with a slope of 40°.

Monitoring Results
Monitoring started at the end of July 2006, thus detailed results are presented for August 2006 onwards. The owner has kept good records of bought energy for the year previous to the
installation, and these values are presented in some of the figures. The amount of log wood used was estimated by the user and the tiled stove using log wood was assumed to have an efficiency of 50%.

Figure 11 shows the REBUS system schematic with sensor positions for the REBUS controller (blue with subscript c) and the monitoring system (red with subscript d). A simple pyranometer has been used to measure the global solar radiation (not shown). The data were logged using a Campbell CR10 data logger with attached multiplexers. Average data values were stored with an interval of one minute.

**Monitoring Demosystem 2006-10-10**

![Diagram of REBUS system](image_url)

*Fig. 11: REBUS system schematic with sensor positions for the REBUS controller (blue with subscript c) and the monitoring system (red with subscript d).*

Figure 12 shows the monthly energy supply to the demonstration house. Autumn 2007 was very mild, with higher ambient temperatures than normal. This is reflected in the relatively low energy supply figures. The electricity supply to the REBUS system was high until the middle of October due to the fact that all auxiliary heat was supplied by electricity as the stove was not yet installed. In all following months, the REBUS system required very little electricity. Almost no auxiliary heat was required during August and September (see more details later).
Fig. 12: Monthly energy supply to the demonstration house (not including the garage) of the REBUS pellet and solar heating system during 2006.

Fig. 13: Monthly energy use for the demonstration house. Wood refers to the log wood tiled oven, and stove to the pellet stove. The first six months are before the SCS was installed. For this period store losses are included in the electricity for SH and DHW.
Figure 13 shows the monthly energy use. The flue gas losses have been estimated based on data from measurements in the lab. The pellets supply was measured manually by the owner. The store heat losses have been calculated based on an energy balance for the store. The hot water use has been more or less constant during the monitoring period, averaging 8-10 kWh/day, although it is slightly larger in winter. The cold water supply temperature to the house varies from 4 to 16°C over the year. The store heat losses are greater in summer than winter, and increased somewhat after December due to a change in control strategy. Before this date the store was only used for solar. After this date a small volume at the top was also heated by the pellet stove in order to give longer running times for the stove. This results in a greater proportion of heat supplied via the radiators than directly from the stove via convection, as can be seen in figure 13. This proportion is still far below the nominal proportion of 65-85% heat supplied to the water, as measured in laboratory tests.

During August the losses were estimated to be on average 100 W (2.4 kWh/day), although this figure has a relatively high degree of uncertainty as it is calculated from the differences of much larger energy quantities.

![Figure 14: Daily energy values for September 2006.](image)

Figure 14 shows the daily energy values for September 2006. The daily DHW load varied from 5.5 kWh to nearly 15 kWh, but was often around 7 kWh. The solar gain was relatively high for most of the month apart from short periods at the start and end of the month. It was only in these periods that any auxiliary heat was required, and this only after several days with low solar gains. This shows a very good function for the whole system and especially the solar heat store, which has a volume of only 360 litres.
Figure 15 shows the daily solar gains as well as the heat delivered from the radiators. Despite the late period of the year a significant amount of solar gain was achieved, especially at the start of the month. The heat flow delivered by the radiators is small, less than 1 kW average for an ambient temperature of -6°C. This is due to the fact that only a third of the total heat delivered to the house comes from the radiators (see figure 16), the majority is coming directly from the stove. Roughly half of the heat generated by the stove goes is transferred to the water circuit, the rest to the room. This is far less than the nominal value of 80% that is typically determined...
for the stove in the lab under constant operating conditions. A detailed analysis of the data revealed that the running time for the stove was very short due to a relatively small standby storage volume and the settings of the wood pellets stove and main controllers. By connecting the standby store slightly differently and by moving one sensor, a reduced number of starts/stops was achieved, resulting in a higher proportion of heat transferred by the radiators and less by convection/radiation. This can be seen from January 2007 onwards.

Fig. 16: Monthly energy balance (values in kWh) for the system in November 2006

Outlook
The demonstration system has been monitored for one full year. Monitoring will carry on for some time to come. Solentek AB and Metro Therm A/S will discuss how to proceed with the further development and commercialisation of the REBUS pellet systems. Relatively little effort is required in terms of development of the system with the separate pellet stove apart from a further analysis and possible changes in the control algorithms for reducing starts/stops. The exact design of the technical unit will also have to be finalised, as there is the possibility of either increasing the standby store, decreasing the height, or using the “unused” volume as some sort of warm cupboard.

More detailed information on the system and its on-site evaluation is available in /Fur07/ which covers both the compact heating unit (REBUS) with gas and pellets auxiliary heater.
Integrated Collector Storage (ICS, Solior)

Also the approach of an "Integrated Collector Storage (ICS) systems" had been identified as a promising system concept. This type of concept combines the hot water store and the solar collector in one element.

Based on this system concept, a product was developed at ECOFYS (figure 17). It consists of a few parts only, many of which are made of polymer material. The essential parts are: A polymer dome which covers a cylindrical tank made of stainless steel and a reflector behind the tank. The system is marketed under the product name Solior.

Both a laboratory performance test and several on-site measurements were carried out (/Sch07/). On-site testing includes a long term test on reliability carried out by ECOFYS, one-year monitoring of two systems installed in Spain and eight installed in the Netherlands. As a result of the various tests of the newly developed system, minor changes were made to the system design. Highlights from the testing are:

Performance test
An official performance test of a prototype according to the European Standard was performed by INETI in Portugal. This outdoor laboratory test was performed according to the European Standard EN 12976-2 – Thermal solar systems and components - Custom built systems - Part 2: Test methods). Table 5 gives some results of the test.

<table>
<thead>
<tr>
<th>Location</th>
<th>Yield (GJ/a)</th>
<th>Yield (kWh/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stockholm (global irradiation: 3.9 GJ/a)</td>
<td>3.081</td>
<td>866</td>
</tr>
<tr>
<td>Wuerzburg (global irradiation: 3.3 GJ/a)</td>
<td>2.640</td>
<td>733</td>
</tr>
<tr>
<td>Davos (global irradiation: 6.0 GJ/a)</td>
<td>4.762</td>
<td>1322</td>
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</table>

With the improvements made for the production model, a 10% higher yield is expected. This has to be confirmed by another performance test which is currently being carried out (summer 2007).

Demonstration project (on-site tests)
Demonstration projects were performed with ten prototype systems. Eight systems were installed in the Netherlands and two in Spain. The project was supported by the EOS-DEMO programme of SenterNovem in the Netherlands. All systems performed well and no repairs were
necessary, only the inner ventilation of the systems was improved during the monitoring year. The hot water demand and the yield of the systems were measured. Figure 18 gives the yield from the monitoring as well as the yield for the systems determined by simulations. For simulations the weather data of the Dutch meteo station the Bilt (2006) was used. On three of the seven systems there was significant shadowing over part of the day. The measured yield shown in figure 18 was corrected to make it comparable with the simulated values. The correction accounts for the differences in irradiation, hot water consumption and shadowing.

![Graph showing yield over the monitoring year (2006) as a function of the hot water demand as well as the results determined by simulation (for the Netherlands boundary conditions.).]

The two systems in Spain were also placed at individual houses. These systems functioned well too. At one of the two sites the occupant even decided to shut off the (natural gas) auxiliary heater from April to October. The heater was switched on again in October because there was a demand for space heating. Apart from this demonstration project there is also a field test running in the Netherlands with a previous prototype. This prototype – monitored by ECOFYS – is working properly until now. Other standardised tests (of reliability and durability) are running.
System concept with water filled collector loop (AquaSystem)

The promising system concepts with water filled collector loop have been introduced successfully into the market during the NEGST project. There are two types which serve different applications:

- Hot water heating (evaluated in the specific report /Abr06-1/, figure 19).
- Water and space heating (combisystem, evaluated in the specific report /Abr06-2/, figures 20 and 21).

Experiences were gained from a large number of systems of both types. Both types were evaluated theoretically which is reported in /Vog06/. The two types of concepts are marketed as “AquaSystem”.

Fig. 19: Hydraulic scheme of the solar system concept with water filled collector loop for DHW-heating. This system concept has been developed by the German company Paradigma. It is introduced to the German market as AquaSystem.

Fig. 20: Solar combi-system concept with water filled collector loop. In this configuration, solar energy is charged into the supply line of the existing heating system.
The most important experiences gained from the installation and the operation of the systems are:

- the marketing advantage due to retrofit compatibility
- the elimination of glycol and its decomposition
- the enhancement of the system availability through auto-diagnostics and stringent problem correction.

These findings were derived from the installation and operation of more than 15,000 systems. They are described in more detail in /Abr07/. 

Fig. 21: Solar combisystem concept with water filled collector loop. In this configuration, solar energy is charged into the return line of the existing heating system.
Compact heating unit for solar domestic hot water preparation (auroCOMPACT)

The compact heating unit, which serves water and space heating and covers an important part of the energy required for water heating from solar collectors had been evaluated theoretically. The evaluation and the system is described in /Vog06/ and a specific report on the theoretical evaluation of the system concept is given in /Ima06/. This system concept was transferred into a product which was installed in large numbers during the NEGST project. Figure 22 shows the unit. It includes the hot water store, the gas heater, pumps, valves and all control equipment required for space and water heating and the connection of solar collectors.

Fig. 22: The compact heating unit marketed as auroCOMPACT is designed to be placed in the living area. © Vaillant

The most important findings from more than 10’000 systems in operation at the end of the NEGST project are:

- the benefits of prefabrication (for easy and safe installation)
- the advantage of the aesthetic design (for marketing)
- performance and comfort gain through the innovative strategy for hot water preparation with the auxiliary heater
- reduced maintenance and improved problem solving through remote surveillance.

These issues are described in more detail in /Ima07/.
DISSEMINATION OF THE RESULTS OF THE ON-SITE EVALUATION

The results of on-site evaluation were presented and discussed at several workshops, conferences and congresses. These events are listed in the NEGST deliverable WP1.D4 (/Vog07/). Results were also disseminated by means of the written documents listed below in the section REFERENCES.

REFERENCES


/Abr07/ Abrecht, S. (2007): WP1.F1 / Experiences from the installation and the operation of the new system generation: solar system concept with water filled collector loop. (/NEGST/).


Further information is available on Project website: http://www.swt-technologie.de/html/negst.html

ACKNOWLEDGEMENTS

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