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Nordic Innovation Centre

January 2007

Solar thermal components adapted to common building standards (SCAS)

- Highly attractive new products for architects, the construction industry and private home owners
- Three new concepts developed for building integrated solar heating system
- Energy savings for solar heating systems is higher than normally anticipated



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Title: Solar thermal components adapted to common building standards (SCAS)		
Nordic Innovation Centre project number: 06037		
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Abstract: Pilot versions of a solar heating/natural gas burner system, of a solar heating/pellet burner system and of a façade/roof integrated polymeric collector have been installed in the summer of 2006 in a number of demonstration houses in Denmark, Sweden and Norway. These three new products have been evaluated by means of measurements of the thermal performance and energy savings of the pilot systems in practice and by means of a commercial evaluation. The conclusion of the evaluations is that the products are attractive for the industry partners METRO THERM A/S, Solentek and SOLARNOR. It is expected that the companies will bring the products into the market in 2007. Further, the results of the project have been presented at international and national congresses and seminars for the solar heating branch. The congresses and seminars attracted a lot of interested participants. Furthermore, the project results have been published in international congress papers as well as in national journals in the energy field. Consequently, the Nordic solar heating industry will benefit from the project.		
Topic/NICe Focus Area: Solar heating systems		
ISSN:	Language: English	Pages: 106
Key words: Solar heating, solar heating systems, solar combisystems, Nordic cooperation, pellet burner system, polymeric collector, thermal performance, energy savings, heating industry, heating, building standards, building materials, solar thermal components, solar energy, renewable energy, architectural solutions, architecturally appealing surfaces		
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Executive Summary

Main objectives

The project had two major aims:

One aim was to influence the development of building standards in the Nordic countries to include standardized solar components, relevant for implementation of new EU-directives for improved energy standard in the building sector. Another aim was to bring the products and components to a stage enabling realistic feasibility studies, and thereby provide the interested industries a basis for in-house product development and commercialization.

Within the project three new developed concepts for solar heating systems were evaluated. The developed systems are highly building integrated solar heating systems: A solar heating/natural gas burner system, a solar heating/pellet burner system and façade/roof integrated polymeric collectors. The products were evaluated by means of monitoring of pilot systems in practice as well as commercial evaluations.

The conclusion of the evaluation was that the products are very attractive. It is expected that the companies METRO THERM A/S, Solentek and SOLARNOR soon will bring the new products into the market. Further, the results of the project have been presented at international conferences, meetings and industrial workshops and published in international and national branch-journals. The Nordic solar heating industry have in this way been informed about the results and it is expected that the results will be used by the industry in the future. Consequently, the objectives of the project have been met.

Method/implementation

Measurements of the thermal performance and the energy savings of three pilot solar heating systems in Denmark, Sweden and Norway have been carried out as parts of ongoing Ph.D. studies at the Technical University of Denmark and at SERC and as part of an ongoing post-doc. study at University of Oslo.

The measurements showed that the developed systems works in a good way, and the measurements from the Danish system indicates that the energy savings for solar heating systems is higher than normally anticipated.

The industry partners METRO THERM A/S, Solentek and SOLARNOR carried out commercial evaluations of the three developed solar heating systems. The evaluations showed that the systems are very attractive.

Concrete results and conclusions

The project has resulted in an excellent cooperation between the participating universities and the industry partners producing the developed products and systems. It is believed that the cooperation will be continued in the future.

New improved solar products and solar heating systems have been evaluated in the project. The products and systems are very attractive compared to products and systems already on the market.

It is expected that the new solar heating systems soon will be brought onto the market by METRO THERM A/S, Solentek and SOLARNOR and that

the documentation of the thermal performance and the energy savings of the systems in practice will be extremely important for the industry in their efforts to promote the solar heating systems.

Recommendations

Worldwide solar energy utilization by means of solar heating systems is one of the most important ways to utilize renewable energy sources today. The solar heating market worldwide is growing by about 30% per year. In Europe the market from 2005 to 2006 had a growth of 50%. It is expected that the market growth will continue. If the Nordic solar heating industry should benefit from the large European solar heating market, it is required that they can offer high quality products. Development of such products must be based on detailed research. Unfortunately the Nordic solar heating industry is relatively weak compared to the solar heating industry in Central Europe. Today it is therefore not possible for the Nordic industry alone to finance the research and development needed to develop competitive solar heating systems for the future. It is therefore strongly recommended that national and Nordic research programs in the future will support solar heating research and development in the Nordic and Baltic countries.

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1 Introduction

Worldwide solar energy utilization by means of solar heating systems is one of the most important ways to utilize renewable energy sources today, [1]. The solar heating market worldwide is growing by about 30% per year [1], while the growth of the European solar heating market from 2005 to 2006 was 50%. The growth is expected to continue. In not a too far future, our energy supply must come from renewable energy systems. Solar heating systems can, if the energy costs from the systems are low enough, play an important role in this connection.

In Europe the largest solar heating markets are present in the Southern and Central European countries like Greece, Germany and Austria. Major companies are active in the market in these countries. The solar heating markets in the Northern European countries are not as good. Only few and small companies are active in the market, and there is a lack of knowledge on solar heating systems in the public and among companies, installers, planners, consultants, architects and decision makers. Further, there is a lack of solar heating experts who can develop solar heating systems for northern latitudes.

In Denmark, Sweden, Norway and Latvia respectively 25%, 23%, 27% and 35% of the country's total yearly energy consumption is used for heating of buildings, while the yearly solar radiation on the horizontal surface of the country is respectively 180, 1030, 1200 and 3130 times greater than the country's total yearly energy consumption. Certainly, the potential for solar heating systems is large, even at northern latitudes.

Recently, increased energy costs have resulted in a strong growth in the small solar heating market in Denmark. Further, it is expected that the newly implemented EU directive 2002/91/EC on Energy Performance of Buildings will result in a stronger market growth in Scandinavia, since both new and renovated buildings must have a low total energy consumption.

The increasing future market in Northern Europe must be based on attractive solar heating systems. Attractive competitive solar combisystems were within the project "Competitive solar heating systems for residential buildings", supported by Nordic Energy Research, developed in cooperation between universities and industries, and solar heating experts, who can work in the solar heating field in the future, were educated.

The project "Solar thermal components adapted to common building standards", SCAS, will hopefully contribute to increased use of the developed systems in the future.

2 Project: Solar thermal components adapted to common building standards (SCAS)

Studies within Task 26 of the International Energy Agency's Solar Heating and Cooling Programme have shown that significant improvements can be made to solar heating systems for combined space heating and domestic hot water supply, and a few German and Austrian companies have already improved their systems, [2]. These improved systems are complete systems including boiler as well as solar collectors, and are often installed in new buildings or when an existing boiler is being replaced. However, these systems are not readily available in the Nordic countries. Therefore it has been decided to use the knowledge gained from this previous international collaboration in connection with development of solar heating systems for North European countries.

During the period 2003-2006, the research project "Competitive solar heating systems for residential buildings" supported by Nordic Energy Research was carried out in cooperation between leading research institutes and companies in the solar heating field in the Nordic and Baltic countries. Within the project new attractive solar heating/natural gas burner systems, solar heating/pellet burner systems and façade/roof integrated polymeric collectors were developed.

During 2006 the project "Solar thermal components adapted to common building standards", SCAS was carried out.

Three prototype versions of the above mentioned products were installed during the summer of 2006 in demonstration houses in Denmark, Sweden and Norway. Measurements of the thermal performance and energy savings of the systems were carried out. Additional commercial evaluations of the three developed products were carried out by METRO THERM A/S, Solentek and SOLARNOR. The evaluations showed that the developed systems are attractive and it is expected that the products will be brought onto the market by METRO THERM A/S, Solentek and SOLARNOR in 2007.

3 Information activities

The project results have been presented on the project homepage: <http://energi.fysikk.uio.no/rebus>. Newsletters with information on the project have been worked out in September 2006 and January 2007.

Further, the project results were presented in the following papers at the EuroSun 2006 Congress in Glasgow, Scotland:

Nordic Energy Research Cooperation on Solar Combisystems, Simon Furbo, Alexander Thür, Frank Fiedler, Chris Bales, John Rekstad, Michaela Meir, Dagnija Blumberga, Claudio Rochas & Björn Karlsson, [1].

The latest solar development in Latvia on solar combisystems, overtaking the barriers. Claudio Rochas, [2].

Design method for solar heating systems in combination with pellet boilers/stoves, Frank Fiedler, [3].

Development of a compact solar combisystem. Alexander Thür & Simon Furbo, [4].

Measurements on a new developed compact solar combisystem in practice. Alexander Thür & Simon Furbo, [5].

Investigation of medium sized solar combi systems. Elsa Andersen & Simon Furbo, [6].

Fabric inlet stratifiers for solar tanks with different volume flow rates. Elsa Andersen & Simon Furbo, [7].

Furthermore, the following articles have been prepared:

Neuentwicklung eines Solarkombi-Kompaktsystems, Alexander Thür & Simon Furbo, Erneuerbare Energie, 2006-2, Zeitschrift für eine nachhaltige Energiezukunft, Publikation der Arbeitsgemeinschaft ERNEUERBARE ENERGIE, [8].

Store besparelser ved nyt solvarmekoncept. Kompakt solvarmeanlæg til kombineret rumopvarmning og brugsvandsopvarmning, Simon Furbo & Alexander Thür, HVAC magasinet 13, November 2006. Magasin for klima- & energiteknik, miljø, bygningsinstallationer & -netværk, [9].

Vai Latvijā pietiek ar Saules siltumu ēku siltumapgādes sistēmai, Klaudio Rošā (Claudio Rochas), EA Enerģētika un Automatizācija, December / January 2006 / 2007. Nr. 10, page 56-59, [10].

Saules kombinētās siltumenerģētiskās sistēmas darbības algoritma un simulācijas modeļa izstrāde, D. Jauzems, C. Rochas, Enerģētika un elektrotehnika, Scientific proceedings of Riga Technical University 2006. Series 4, Nr. 17, page 133-143, [11].

Sol til varme og kulde. Trond M. Hansen interviews John Rekstad, Bilag in AFTENPOSTEN in Nov. 2006 by NextMedia AS, pp 10-11, [12].

Building integration of solar thermal collectors. Coloured brochure within the EU-project NEGST, describing among others the Norwegian demonstration solar heating system in the projects REBUS & SCAS, [13].

Finally, the following meetings and workshops with presentations on the project results have been organized:

April 5: Presentation for Norwegian engineers within VVS at "Ingeniørenes hus" in Oslo, Norway, 30 participants.

April 27-28: Presentation for participants at the IEA-Task 39 "Polymeric materials in Solar thermal applications" in Leoben and Blumau, Austria, 40 participants.

May 12, SAFE Industrifagdag, Aud. 2, Georg Sverdrups Hus, University of Oslo, Norway, 70 participants.

June 2: Presentation for Enova in joint meeting for all employees in Trondheim, Norway, 30 participants.

September 7: Presentation for "lektorer og lærer i vidergående skole" at the University for Life Sciences at Ås, Norway, 50 participants

October 27: Solar seminar at Riga Technical University, Environmental and Energy Institute, Riga, Latvia, 19 participants.

October 31: Presentation at the the Institute of Energy Technology (IFE) at Kjeller, Norway, 20 participants.

November 8: Presentation for university teachers and scientists from the University for Life Science (Ås) at the University of Oslo, 20 participants

November 13-14: Project meeting at Technical University of Denmark, Denmark, 11 participants.

November 14: Solar heating seminar, Technical university of Denmark, Denmark, 75 participants.

November 28: Solar heating seminar, Örebro, Sweden, 70 participants.

December 12: Presentations for participants of the seminar “Sustainable development in the Nordic Countries and in Latvia” organised by Norden, Nordic Council of Ministers’ Office in Latvia, 102 participants

4. Conclusions

The project has increased the cooperation within the solar heating field between the Nordic and Baltic universities.

It is expected that the attractive solar combisystems evaluated in the project will be brought to the market by METRO THERM A/S, Solentek and SOLARNOR. Consequently, the project will contribute to increased use of solar heating systems in the future.

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Appendix 1: Activities at Technical University of Denmark

Introduction

The developed solar heating system and the demonstration system inclusive measurements from this system will be described in the following. The Ph.D. report describing all project activities will be finished in February 2007.

Description of developed system

A solar heating/natural gas heating system was developed. The simplified hydraulic scheme of the developed concept is shown in figure 1. The system consists of two units, the “Solar Store Unit” and the “Technical Unit”. The “Solar Store Unit” in principle is a buffer tank filled with space heating water which needs to have 5 connections at the right heights. For this “Solar Store Unit” any simple available tank can be used because all advanced devices for optimized operation of the system are integrated in the “Technical Unit”. Of course also more advanced tanks with e.g. stratification devices can be used as well. The “Technical Unit”, so to say, is the heart of the whole system. In this prefabricated unit all components needed to operate the solar heating system are integrated. These are mainly the central controller, the condensing natural gas boiler, domestic hot water flat plate heat exchanger, solar flat plate heat exchanger, expansion vessels for the tank and the solar collector loop, pumps and all necessary mixing and switching valves.

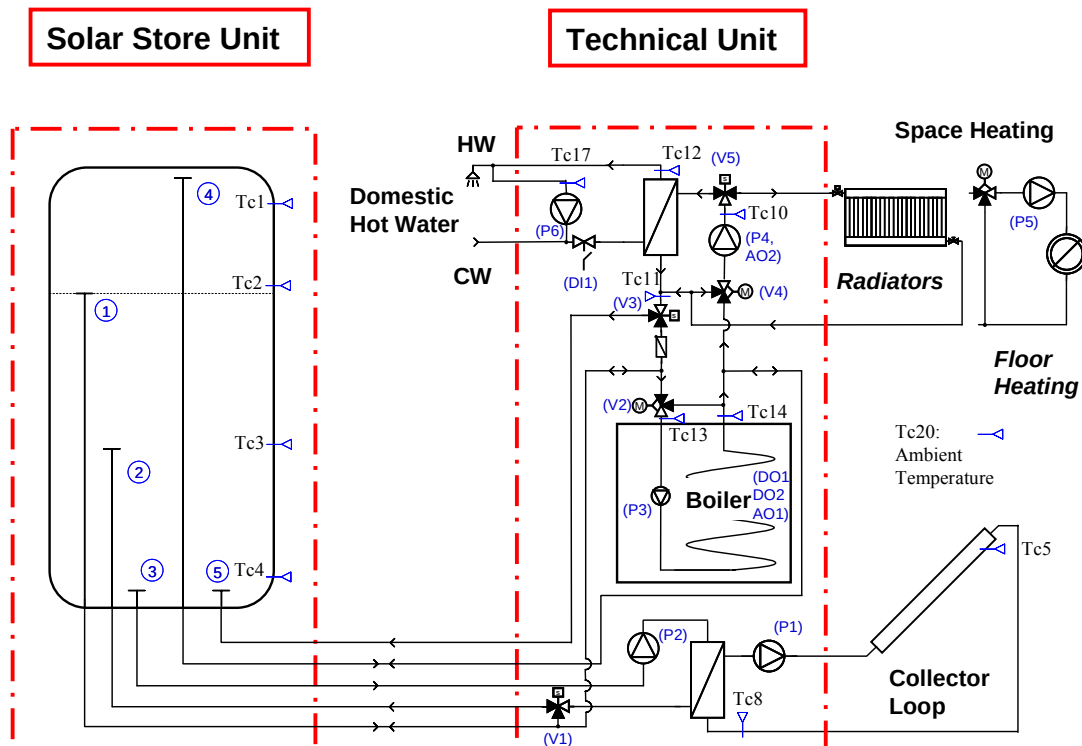


Fig.1 Principle hydraulic scheme of the solar combisystem concept

Operation tasks of the system

The operation of the system can be separated in six operation tasks, each of them can be active for itself or two or more are active in parallel. The six operation tasks are:

1. Domestic hot water preparation
2. Domestic hot water circulation
3. Space heating
4. Boiler at low temperature for space heating
5. Boiler at high temperature for domestic hot water preparation or space heating
6. Solar heating

Domestic hot water preparation

If domestic hot water is used the flow sensor at cold water (CW) inlet is activating the domestic hot water preparation. The switching valve (V5) immediately is switching to the domestic hot water heat exchanger, the pump (P4) starts running and the mixing valve (V4) is controlling the primary forward temperature depending on the controller settings. Pump (P4) is speed controlled that way, that the hot water (HW) temperature is kept constant at the set temperature. Both the pump (P4) and the mixing valve (V4) are controlled by a PID controller which is integrated in the central system controller. Hot water is taken from the highest point in the tank (pipe 4) passing the mixing valve (V4), the pump (P4) and the switching valve (V5) to enter the domestic hot water heat exchanger. After the heat exchanger, depending on the return temperature and the actual temperature stratification in the tank, the cold water is stratified into the tank by the valve (V3) via pipe 5 or pipe 1.

In the controller it is possible to define the set temperature for the tap hot water (HW). Also a temperature difference can be defined which the hot water temperature at the primary side of the heat exchanger shall be higher than the tap hot water.

Domestic hot water circulation

The domestic hot water circulation pump (P6) in general can be activated by several time windows which can be defined in the controller. Two different operation modes are possible:

1. Keep the domestic hot water pipes warm within defined time windows
2. Hot water circulation on demand

The first strategy is starting the hot water circulation pump (P6) if the circulation temperature is decreasing below a set start temperature and stopping when the circulation temperature is increasing above a set stop temperature.

The second strategy is starting the hot water circulation pump (P6) when the flow sensor indicates hot water tapping. Therefore with a short opening of any tap valve in the house the circulation pump is started. If the circulation temperature is increasing above a set stop temperature the circulation pump stops.

Space heating

Space heating can be switched on or off in the controller by a parameter or automatically activated if ambient temperature or room temperature is measured

to be below a set value. Space heating forward temperature is controlled via a so called “heating curve” depending on the ambient temperature. This heating curve can be defined in the controller. The speed of the pump (P4) during space heating operation is constant and can be defined as a parameter in the controller. The actual flow rate is controlled by thermostatic valves and/or pre adjusting valves in the space heating system.

Hot water is taken from the highest point in the tank (pipe 4) passing the mixing valve (V4), the pump (P4) and the switching valve (V5) to enter the space heating system. Depending on the return temperature after the radiators or the floor/wall heating and the actual temperature stratification in the tank, the cold water is stratified into the tank by the valve (V3) via pipe 5 or pipe 1.

Boiler at low temperature

Condensing natural gas boilers typically have two hydraulic connections in combination with two operation modes, the space heating mode and the domestic hot water preparation mode. Space heating mode typically is activated by a room thermostat and the domestic hot water preparation mode is controlled by a temperature sensor in the hot water tank. In this case the central controller is controlling the two inputs of the gas boiler controller instead of connecting a room thermostat and a hot water temperature sensor.

If during space heating the temperature in the top of the tank (pipe 4) is not high enough the boiler is activated. If the demanded space heating forward temperature (depending on the heating curve) is below a defined set temperature, the boiler is allowed to operate at the low temperature level (typically between 40 and 50°C) in the space heating mode. This gives the condensing natural gas boiler good operation conditions for condensation since the dew point of the exhaust gas is about 57°C.

Cold water is taken out of the tank via pipe 1, passing the mixing valve (V2) and entering the boiler. The hot water coming out of the boiler is stratified into the tank via the highest inlet, which is pipe 4. In parallel also hot water coming out from the boiler is directly used for space heating with the demanded flow rate. Since the boiler always has a higher flow rate than space heating, the auxiliary volume in the tank (volume between pipe 4 and pipe 1) is heated up. If the temperature at the level of pipe 1 approaches the switch off set temperature, the boiler is switched off. Due to this concept of parallel flows, several advantages are achieved. The boiler is not forced to operate below its minimum flow rate, which ensures that an internal bypass valve (which is existing in most condensing natural gas boilers) is not opened and therefore not raising the return temperature which would reduce the condensation rate. Due to the possibility to use the auxiliary volume, the boiler also is not forced to operate below its minimum power which the boiler can reach by modulation. This is strongly reducing the start/stop frequency and therefore also raising the boiler efficiency and reducing exhaust gas emissions.

Boiler at high temperature

If during domestic hot water preparation the temperature in the top of the tank (pipe 4) is not high enough the boiler also is activated, but now at high temperature level in domestic hot water mode which is needed to be able to prepare domestic hot water at the desired tap temperature. Since tap temperature

typically is between 45 and 55°C the boiler set temperature at high temperature level must be about 55 to 65°C.

If during space heating the demanded space heating forward temperature (depending on the heating curve) is above a defined set temperature the boiler also is forced to operate at the high temperature level in the domestic hot water mode.

Due to the high boiler forward temperature it could be expected, that the condensation rate of the natural gas boiler is very low. But thanks to the high flow rate and the very low return temperature during hot water preparation, also in this high temperature operation mode good condensation can be achieved mostly.

Solar heating

If the temperature sensor in the solar collector exceeds the temperature in the bottom of the tank, the primary solar pump (P1) starts running. When the primary solar forward temperature at the inlet of the solar heat exchanger also is high enough the secondary solar pump (P2) is starting. Cold water is taken from the tank via pipe 3 and depending on the existing temperature stratification in the tank the solar heated water is stratified back into the tank by the switching valve (V1) via pipe 2 or pipe 1.

Solar Store Unit

Based on the 300 liter standard domestic hot water tank from Metro Therm A/S this solar store unit was developed. This standard tank is integrated in a 60 x 60 cm cabinet with a nice casing which is perfect for optical integration. The standard tank is insulated with PUR-foam which is filled between the tank with a diameter of 500 mm and the 60 x 60 cm cabinet. The minimum insulation thickness therefore is 50 mm. At the top of the tank the insulation thickness is also about 50 mm. All pipe connections are placed at the bottom of the tank, using internal PEX pipes to reach the different levels in the tank. Only small holes in the insulation at the top of the tank are needed to mount the temperature sensors. These holes are reducing the insulation quality only very little, because the two thin cables are just marginal thermal bridges.

According to Metro Therm A/S the overall heat loss coefficient of this standard tank is 2.9 W/K.

Improvement of the standard tank design

In order to improve this standard tank to be used in a solar combisystem, several changes in the tank design were done which are described now:

The volume of 300 liter for a solar combisystem, even a small one, is too little. To increase the volume but still to keep the 60 x 60 cm concept, a new combined insulation concept was developed to be able to increase the diameter of the tank. Using 20 mm thick vacuum panels, see figure 2, which are integrated into the PUR foam allows to increase the diameter of the tank by 10% (550 mm instead of 500 mm) which increases the volume by 20% (360 liter instead of 300 liter) but having about the same heat loss coefficient. Detailed investigations of the heat loss coefficient are presented later.

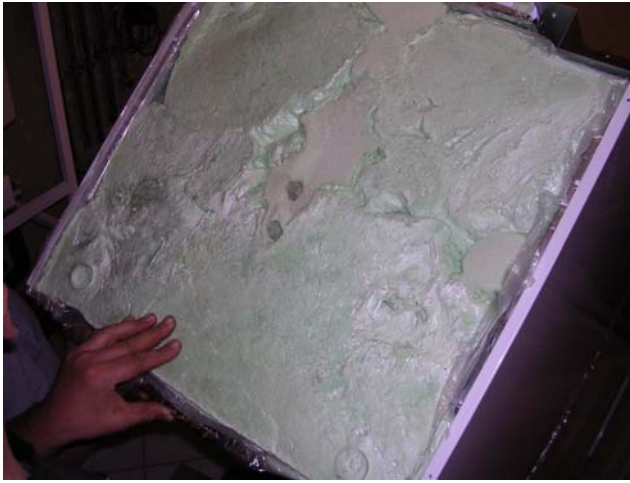


Fig.2 Left: View on the top of the tank with vacuum panels at the sides and the 2 small holes for the temperature sensors in the middle of the tank; Right: View at the front of the tank without the cover plate to see one of the vacuum panels.

Since the store is filled with space heating water instead of fresh water, it is possible to cancel the as a standard existing internal enamel protection layer, which reduces costs.

All pipe connections are at the bottom of the tank. PEX pipes with 16 mm inner diameter and 20 mm outer diameter that fit exactly into the $\frac{3}{4}$ " steel pipes, which are welded into the bottom of the tank, are used to reach to the right level in the tank. Investigations showed that the wall thickness of 2 mm should be enlarged to reduce the heat transfer coefficient between the tank water and the water inside the PEX pipe to minimize unintentional heat transfer which would have several negative effects. For that reason a second PEX pipe with 22 mm inner diameter and 32 mm outer diameter is used for additional insulation for the long pipes No 1 and No 4 which are reaching the top part of the tank, see figure 3.



Fig.3 Prototype example showing a thin PEX pipe (with holes at the end) with an additional thick PEX pipe to decrease the heat transfer coefficient.

A drawing of the tank is shown in Fig.4. Pipe 1 and pipe 4 have this additional thick PEX pipe. Pipe 1 at the end is closed to prevent vertical flow into the tank which could cause strong turbulences. Water can enter or leave the tank through the holes which are radially drilled into the PEX pipe. Pipe 4 in the end has a T-piece in order to have low and horizontal inlet velocity when water is entering the tank which shall guarantee good stratification. Pipe 2 is only a thin PEX pipe

again with radially drilled holes. Pipe 3 has no PEX pipe, it is just the $\frac{3}{4}$ " steel pipe which is welded into the bottom part of the tank. Pipe 3 is only used to take out water from the tank to be heated by the solar collector. Pipe 5 is the low temperature inlet pipe which also has a T-piece in order to guarantee good stratification when cold water is entering the tank. During hot water preparation this inlet pipe 5 can have the highest inlet flow rates which typically can take place, that's why the T-piece here is very important.

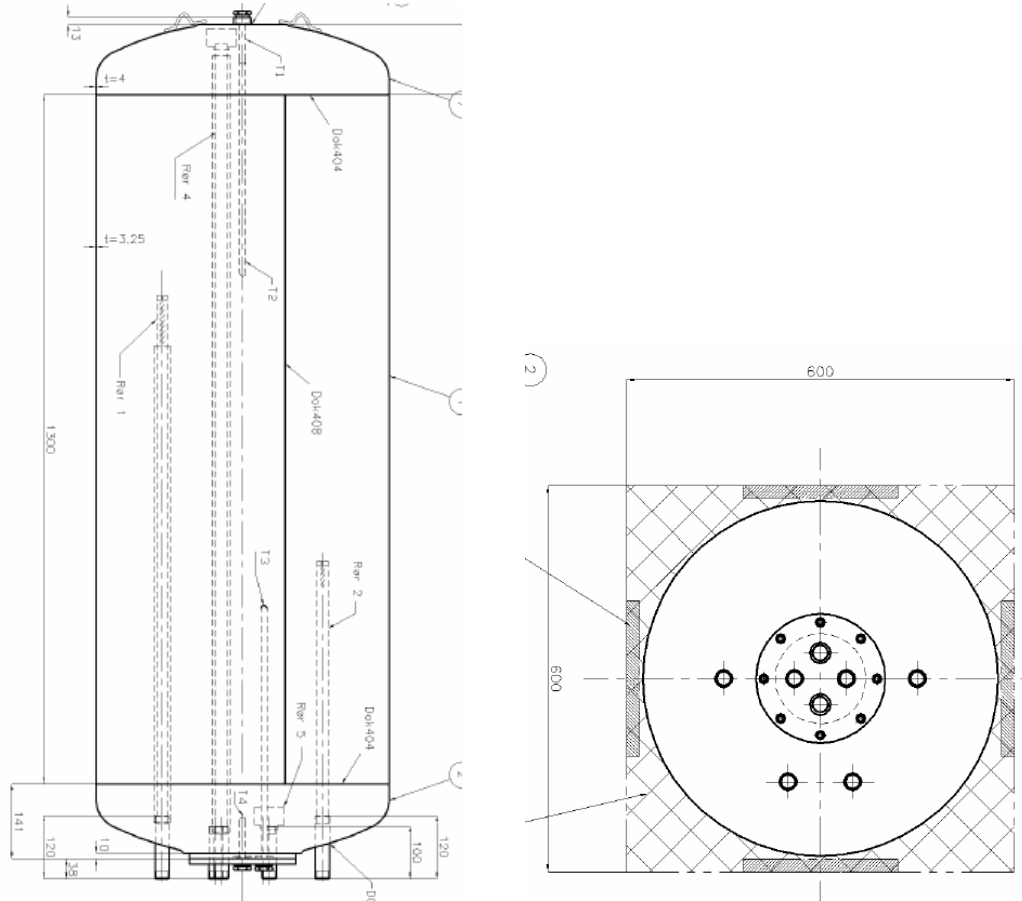


Fig.4 Left: Drawing of the solar tank including the internal pipes No 1-5 and the temperature sensor sockets T1-T4; Right: the tank with the vacuum panels on four sides integrated in the PUR foam.

Heat loss coefficient of different tank designs

In order to investigate the influence of the different tank designs relating to volume and heat losses some calculations with the finite element program THERM were done. A large tank diameter (550mm) with less insulation thickness (minimum = 25mm) but using vacuum panels was compared with a smaller tank diameter (500mm) with more insulation thickness (minimum = 50mm). The following main parameters were used for the calculations:

Tank diameter: 550mm (in case 6: 500mm)
 Cabinet dimensions: 60 x 60cm (in case 5: 65 x 65cm)
 Total insulation thickness on thinnest position: 25mm (in case 5 and 6: 50mm)
 Temperature inside: 60 °C; film coefficient: 1000 W/m²K
 Temperature outside: 20 °C; film coefficient: 8 W/m²K

Foam: Polyurethane (PUR) Foam, thermal conductivity: 0.024 W/mK

Vacuum panels, thermal conductivity: 0.005 W/mK;

Dimensions of the vacuum panel: 10mm x 200mm x 1000mm

In Figure 5 the tank with the rectangular 60 x 60cm cabinet is shown. Due to symmetry of the geometry, only the colored part is needed to be calculated. The yellow marked part represents PUR foam, the small grey and green parts are filled with PUR foam, vacuum panel(s) or air, depending on the goal of investigation.

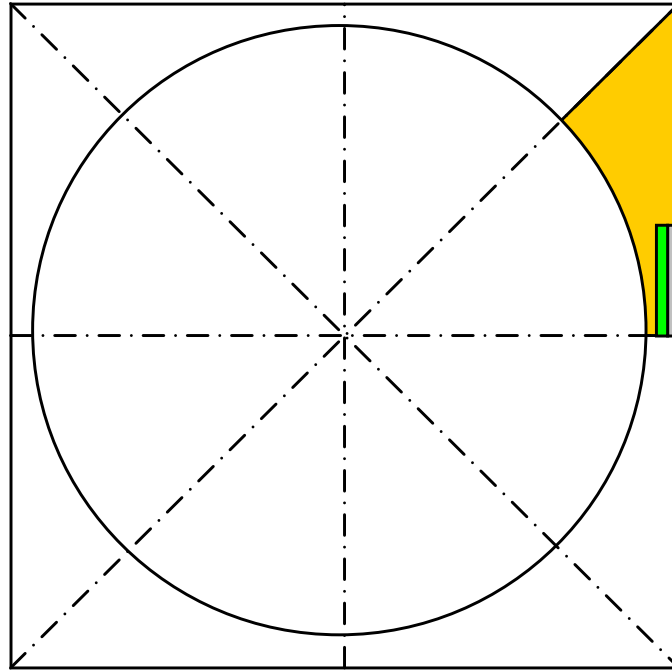


Fig. 5 Tank model with the colored sector which was calculated.

The results of six different cases which were investigated are summarized in Table. Base case is case No 6, a tank with 500mm diameter surrounded by PUR foam within a 60 x 60cm cabinet. The finally realized tank design is based on case No 3, where 20mm thick vacuum panels are used.

Table 1 Heat loss coefficient (U-value) of 1m tank height with different insulations and PUR foam with $\lambda = 0.024 \text{ W/mK}$

No:	Tank diameter [mm]	Insulation thickness at thinnest place [mm]	Foam thickness [mm]	Air thickness*) [mm]	Vacuum panel thickness [mm]	U-value [W/K]	Change in [%]
1)	550	25	25	0	0	0.94	165
2)	550	25	15	0	10	0.65	113
3)	550	25	5	0	20	0.55	96
4)	550	25	5	10 *)	10	0.68	119
5)	550	50	50	0	0	0.61	107
6)	500 **)	50	50	0	0	0.57	100

*) In case No 4 an air bubble is calculated for the whole height between a 10 mm vacuum panel and the tank. This is a very bad worst case scenario for the case that during foaming an air bubble is left somewhere.

**) Base case

These calculations are only done for the energy losses of a 1m high cylindrical part of the tank sides. The top and bottom parts of the tank are not included in these investigations.

Comparing case No 3 and base case No 6 shows, that using a 20mm vacuum panel the tank with 20% more volume due to 10% larger diameter, within the same 60 x 60cm cabinet will have 4% less heat losses from the tank sides compared to the small standard tank. If only the 10mm vacuum panel is used, then the heat losses of the tank sides will increase by 13% (compare case No 2 and case No 6).

Due to problems during the foaming process it might be possible that air bubbles will appear between the vacuum panel and the tank. Therefore case No 4 was defined as a worst case scenario using only 10mm vacuum panel and assuming a 10mm air bubble instead of the inner vacuum panel. Comparing case No 3 and case No 4 shows that in the worst case scenario this huge air bubble between the tank and the vacuum panel is increasing the U-value from 0.55 to 0.68W/K or 23% respectively. This U-value is still much less compared to case No 1 without vacuum panel. In fact the air bubble(s) due to production failure are much smaller, so it can be assumed that the influence will be much smaller. Of course this is only valid, if the air bubble is closed and has no connection to outside so that no air flow can occur.

As an example in figure 6 the results of case No 3 are presented. In the graph on the right side of the figure the isothermal lines are shown.

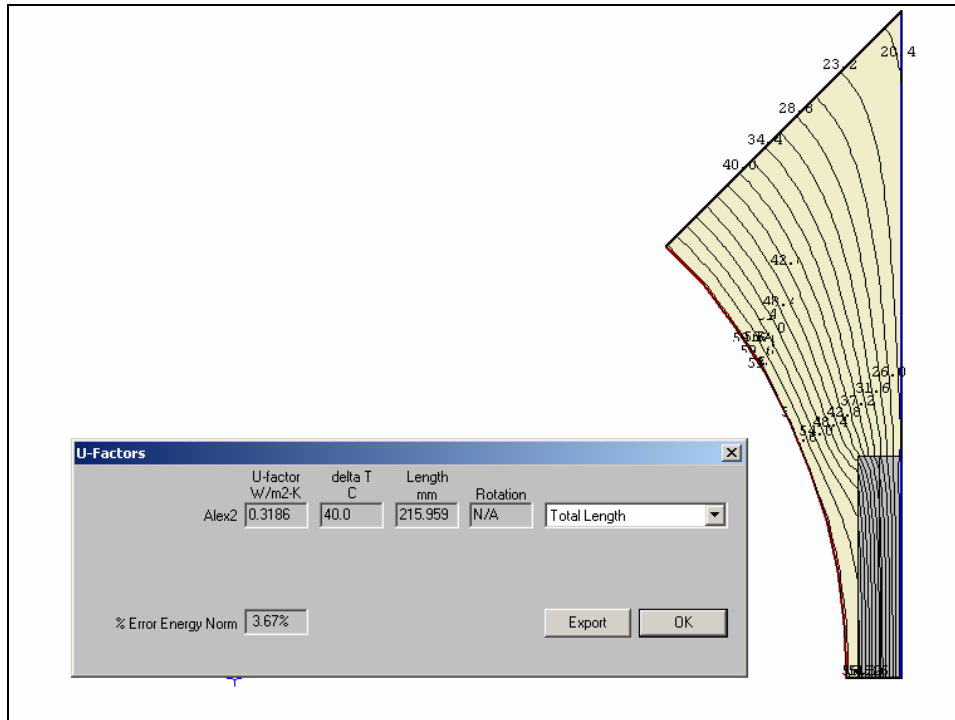


Fig. 6 Calculation results of case No 3.

Technical Unit

The technical unit is a prefabricated cabinet, again with the measures of 60 x 60cm and containing all components which are needed to run the solar combisystem. The unit prepared to be installed in the first demonstration system is shown in figure 7.



Fig. 7 Technical Unit, ready for installation in the demonstration house.

In the top of the cabinet the condensing natural gas boiler is mounted. Below the boiler in the front the expansion vessels for the solar tank (the 3 red ones) and for the solar collector loop (the 2 white ones) are mounted. They can be removed easily without disconnecting the pipe connections to get access to all the

components in the back where all the components like pumps, heat exchangers, mixing and switching valves, etc. are installed. Finally the technical unit looks like in the demonstration house, shown in figure 8 on the right side.



Fig. 8 Installation of the complete system before (left) and after (right) installing the cover plates.

The special characteristics and advantages of this prefabricated technical unit are:

- All components are included in the two cabinets making the whole installation nice looking and therefore acceptable for installations in daily used rooms like entrance room, bath room, kitchen, etc.
- Reducing the installation time on construction site and due to the cabinet it is easy to transport the units.
- Reducing the possibilities of mistakes during installation due to high degree of prefabrication.
- In spite of the prefabrication still it is possible for the customer to choose different suppliers for the tank and/or the boiler which are the most costly single components.
- The technical unit can be operated also independently from the tank which gives the possibility to invest step by step. First only the technical unit can be installed, which is supplying the house with hot water and space heating and as a second step the solar tank and the solar collector can be added.
- Minimizing the pipe length within such a compact system is resulting in faster reaction and lower heat losses of the whole system.
- Due to the closed cabinet the ambient temperature for all not insulated components is higher and therefore the heat losses are lower. The insulation of the flat cover plates of the cabinet is much easier than all the single pipes and components and therefore cheaper.
- Due to the special design of the hydraulic system and the control algorithm this system can be operated in combination with a high peak power condensing natural gas boiler in a very special way which leads to highest system efficiency. This means that the natural gas boiler has a peak power of about 30kW, which enables to prepare domestic hot water directly without keeping the auxiliary volume of the tank at a high temperature level.

The technical unit and the controller are also prepared to operate in combination with different auxiliary heat sources than high power condensing natural gas boilers. In addition also low power condensing natural gas boiler, pellet boiler, oil boiler or district heating can be used as auxiliary heat source. The difference is just in a parameter setting of the controller and then the auxiliary volume is kept hot at a sufficient high temperature to ensure high enough hot water power at any time. With the advantage to use a larger auxiliary volume the hydraulic scheme in this case looks like shown in figure 9. The difference to figure 1 is just that pipe 1 is shorter and the temperature sensors Tc1 and Tc2 are positioned lower.

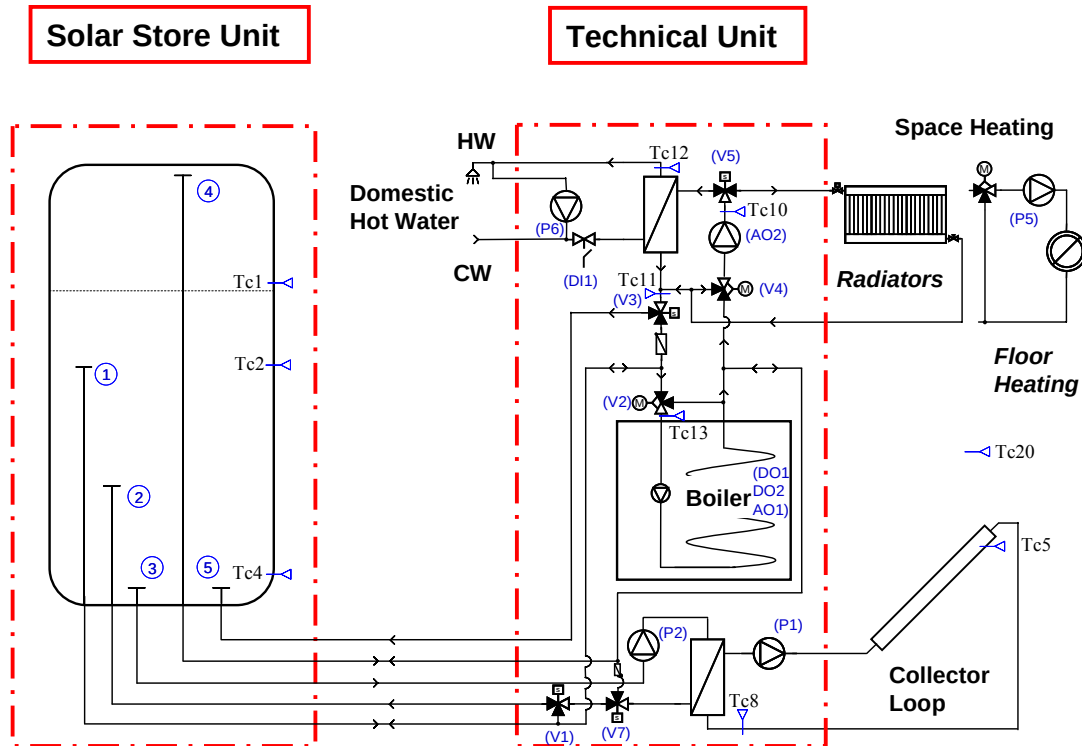


Fig. 9 Principle hydraulic scheme of the solar combisystem concept with enlarged auxiliary volume.

Possible options of the hydraulic scheme

The controller is also prepared to operate in combination with more than one tank. For example it is possible to integrate an auxiliary tank of about 80 liter in the technical unit instead of the gas boiler, see figure 10, left as it was done by the Swedish project partner SERC for their demonstration system in combination with a pellet stove. For a more advanced and compact technical unit in combination with a pellet boiler a compact 80 liter tank with a cubic shape was used at SERC as a prototype shown in figure 10 at the right side.



Fig. 10. Left: Top of the technical unit with a standard 80 liter auxiliary tank instead of a gas boiler. Right: Prototype of a technical unit at SERC with a cubic 80 liter tank in the top and an adapted pellet stove below.

The hydraulic concept in this case has to be changed only very little as shown in figure 11. In practice the auxiliary tank hydraulically is just added at the top of the solar tank. In order to be able to heat the auxiliary tank also by solar energy, it is possible to add the switching valve (V7). Otherwise in a more simple and cheaper way also the switching valve (V1) could be used when the two outlets are interchanged in their functionality (the pipe 2 outlet has to be changed to the auxiliary tank and now is the high temperature outlet).

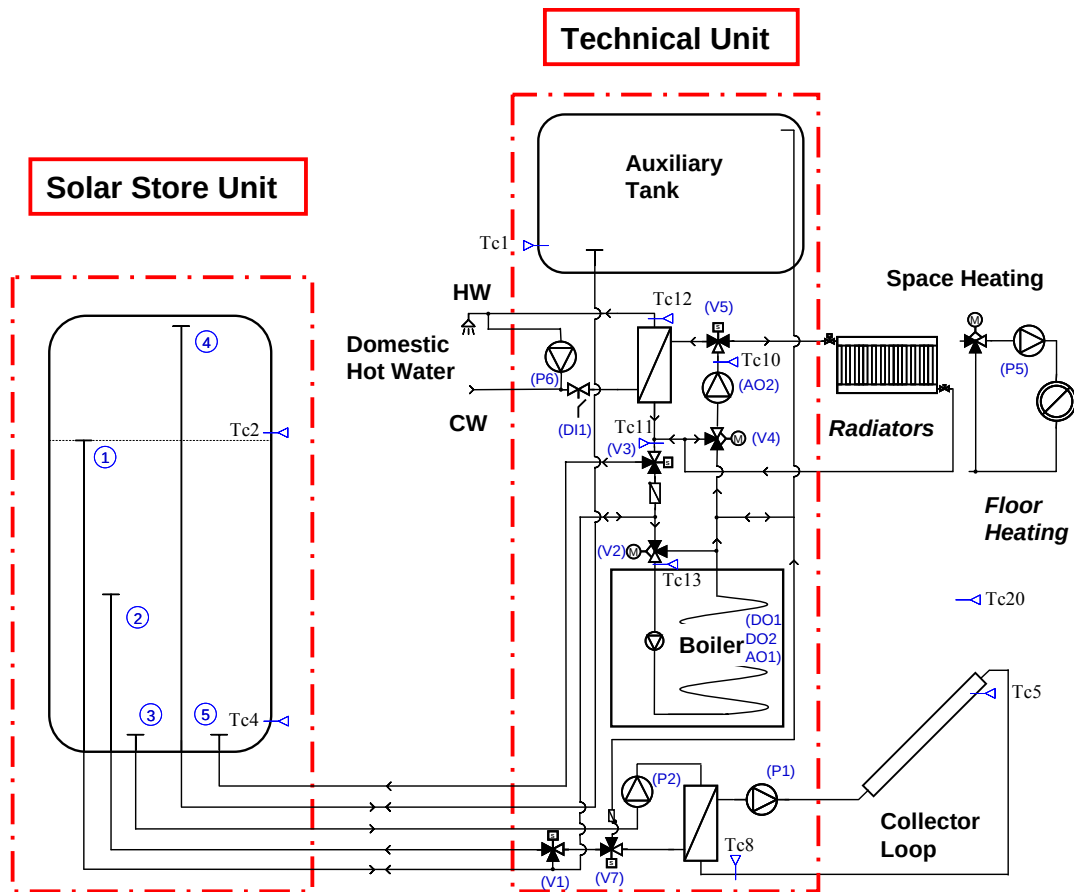


Fig. 11 Principle hydraulic scheme of the solar combisystem concept with auxiliary tank.

Of course the auxiliary tank also can be realized in full size as a second solar tank in order to increase the heat storage capacity more significantly as shown in figure 12. This scheme is designed to be used again in combination with a fast reacting natural gas boiler. To be able to use the two tank scheme in combination with a pellet boiler only a parameter in the controller must be switched and the length of pipe 1 reduced and the temperature sensors Tc1 and Tc2 must be positioned lower like shown in figure 13.

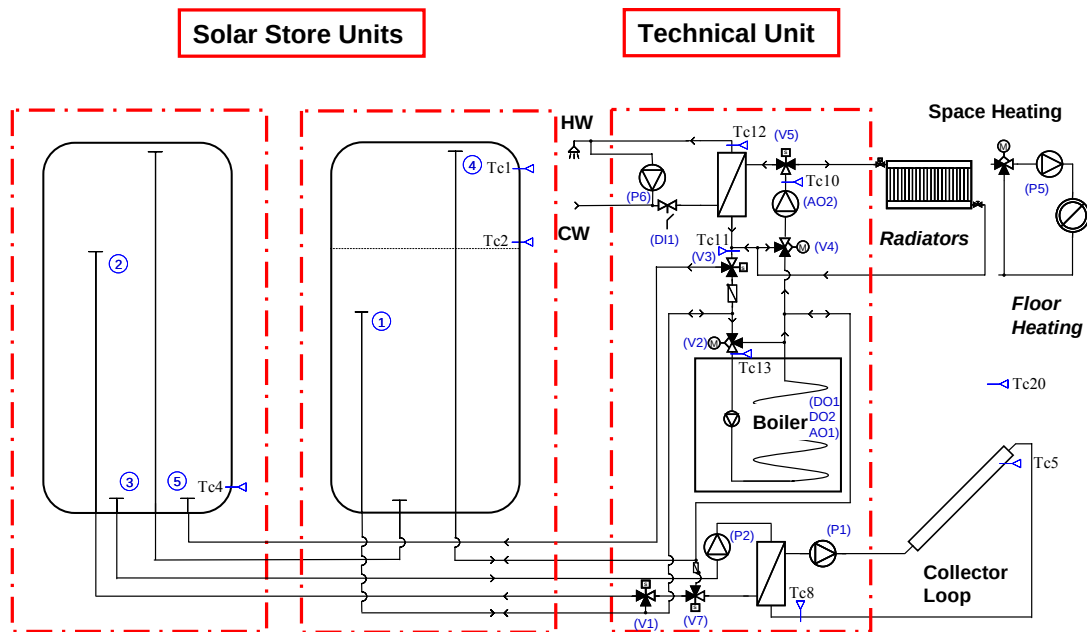


Fig. 12 Principle hydraulic scheme of the solar combisystem concept with two tanks to be used with a fast natural gas boiler.

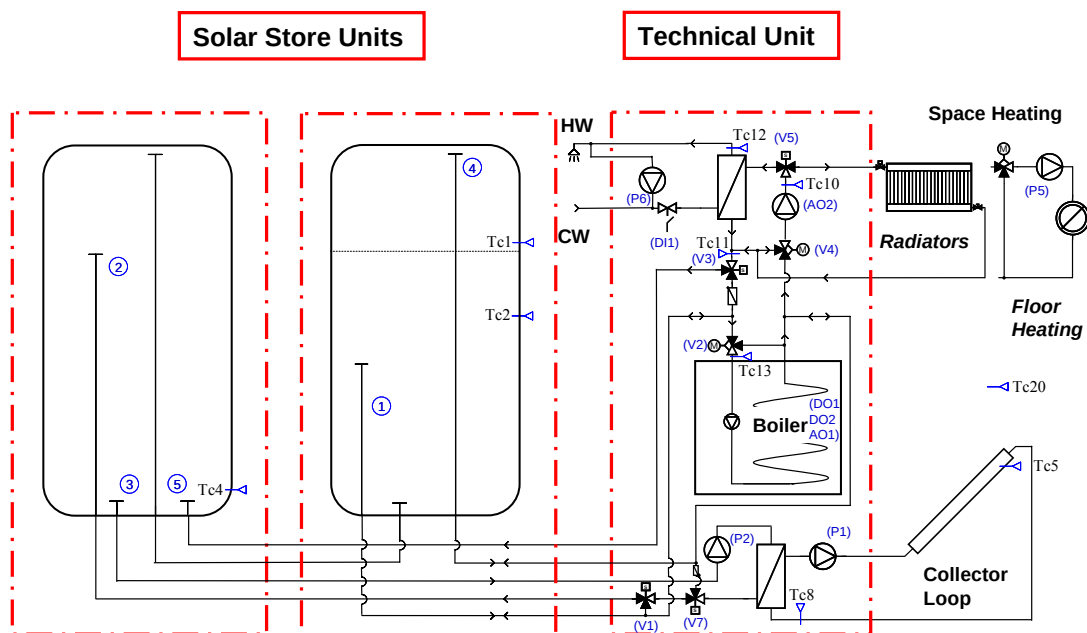


Fig. 13 Principle hydraulic scheme of the solar combisystem concept with two tanks to be used with a pellet boiler.

Demonstration house

In parallel to developing and testing the first prototype of the solar combisystem in the laboratory, a one family house was found where the house owner was willing to get the second prototype installed. To be able to compare the natural gas consumption and the electricity consumption for operating the heating system of the house with the old existing heating system and the new solar combisystem, in August 2004 measurements started in this demonstration house. This first period of measurements took place until April 2006, therefore a period of 21

months could be evaluated based on measurements of the old heating system with a non condensing natural gas boiler. From June until July 2006 the new solar combisystem was installed and then again measurements were started.

Description of the demonstration house

The demonstration house is situated in the small town Helsingør, about 40 km North of Copenhagen ($56^{\circ}01' \text{ N}$, $12^{\circ}12' \text{ E}$) and it is occupied by two adults and one teenager. The house shown in Fig. 14 has three floors: the basement with 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.



Fig. 14 View on the demonstration house from the south.

The space heating system mainly consists of several old cast iron radiators, Fig. 15, left. The bedroom in the basement has floor heating with an extra pump with integrated mixing valve which is controlled by a room temperature sensor. The floor heating loops, each with a return temperature control thermostat valve, are in the entrance room and the bathroom in the basement and in the bathroom in the second floor.



Fig. 15 Cast iron radiator in the dining room (left), the pump with integrated mixing valve for the bedroom in the basement (middle) and the return flow control thermostat valve for the floor heating in the bathroom in the basement (right).

The following three sketches, figure 16, 17 and 18, show the layout of the three floors. The following abbreviations are used in these sketches:

- R – Radiator: white = in use; black = not used
- GB – Gas boiler
- FH – Floor heating
- DHW – Domestic Hot Water tank
- P3 – Pump of floor heating in the bedroom in basement

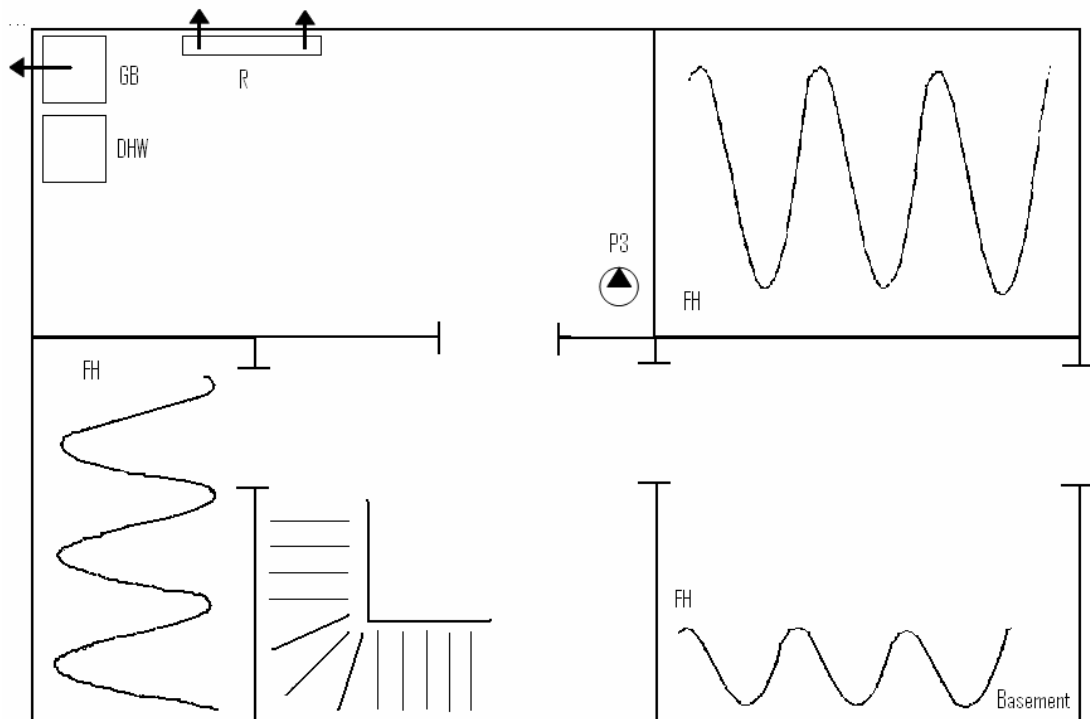


Fig. 16 Basement of the demonstration house.

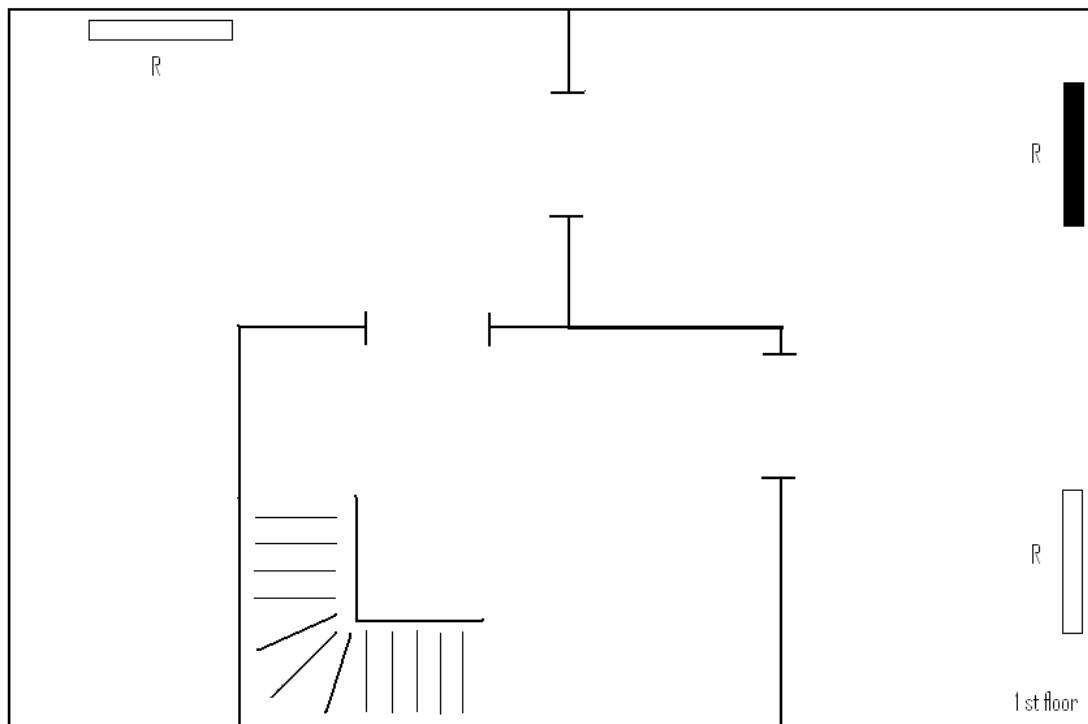


Fig. 17 First floor of the demonstration house.

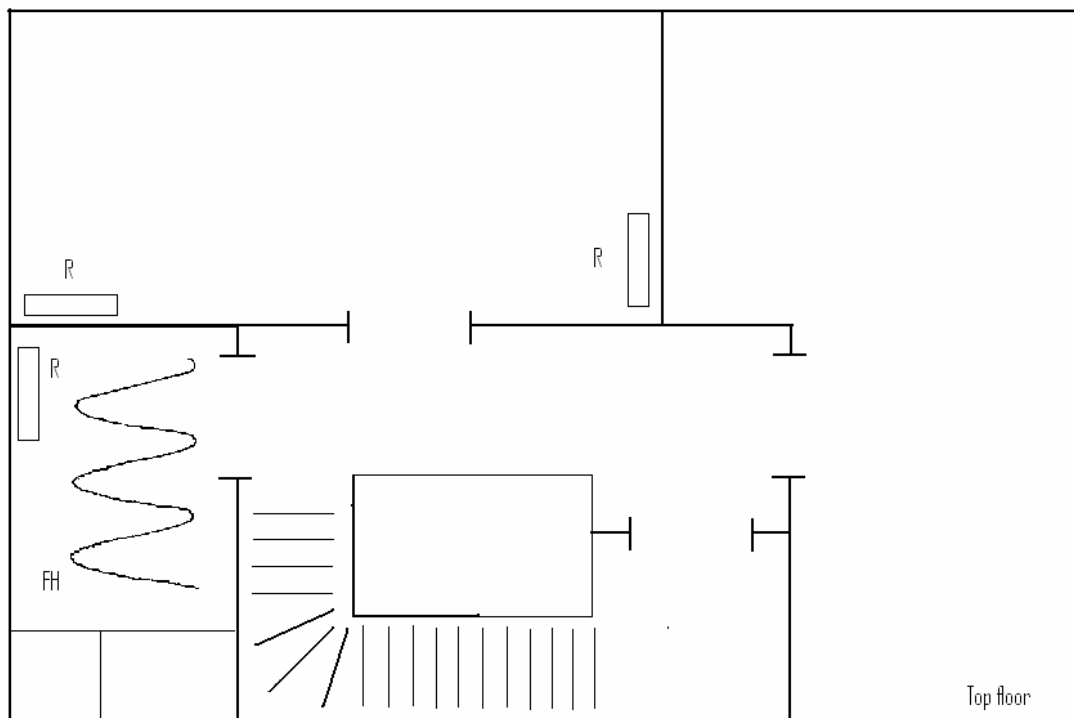


Fig. 18 Second floor of the demonstration house.

The old natural gas heating system

The old heating system 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, see figure 19.

- Natural Gas Boiler: Vaillant, Nominal Power: 22 kW; Construction year: 1990

- Domestic hot water tank volume: 60 liter
- Number of pumps: 3; The main pump is integrated in the gas boiler, one extra pump for the floor heating in the bedroom in the basement and one hot water circulation pump.



Fig. 19 The non condensing natural gas boiler (right) and the hot water tank (left).

The hydraulic scheme for the old heating system is shown in Fig. 20. In the house in total seven radiators are installed, all of them are equipped with a thermostat valve with an integrated room temperature sensor. The bedroom in the basement has floor heating with an extra pumped space heating loop where the room temperature is controlled by a room temperature sensor which is controlling the mixing valve. Further three more floor heating loops are installed in the two bath rooms and in the entrance room in the basement. All three floor heating loops are equipped with a thermostat valve which is controlling the return temperature.

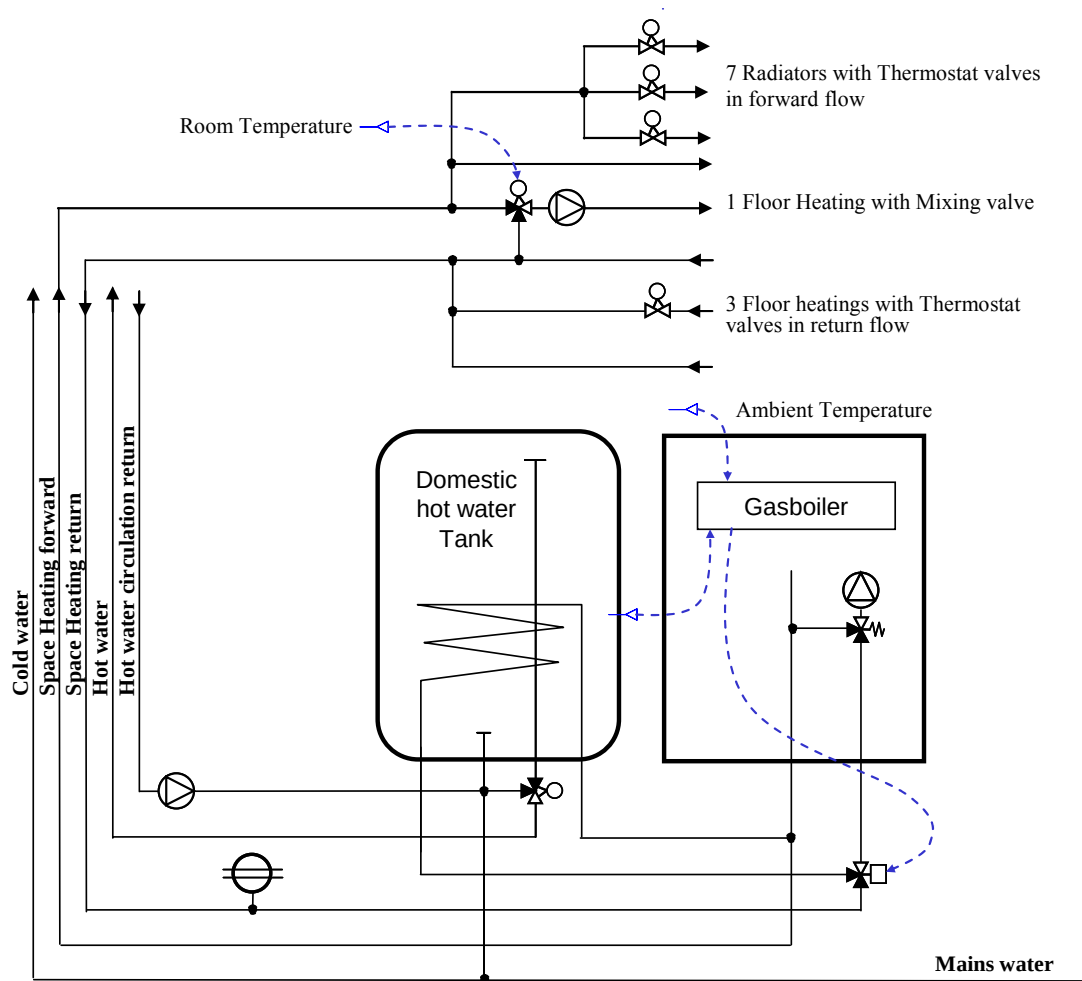


Fig. 20 Hydraulic scheme of the old heating system.

In principle an ambient temperature sensor was connected to the controller of the boiler. But as described later, the controller did not work properly in space heating mode.

The hot water circulation pump was not connected to electric power for a long time. After setting the pump in operation (21/11-2005; daily from 6-8 and 17-20) and getting the experience that the energy losses are huge, the house owner decided to switch it off (20/12-2005) again.

The new installed solar combisystem

In June and July 2006 the new solar combisystem was installed. In Fig. 21 the demonstration house with five VELUX S08 collectors with in total 6.75 m^2 collector area (8 m^2 gross collector area) on the roof and the two 60×60 cabinets with a 360 liter solar tank installed in the basement are shown.



Fig. 21 Demonstration house with the collectors mounted on the roof (left) and the installed solar tank unit and the technical unit in the basement (right).

General main data:

Geographic position of the house: 56°01' N and, 012°12' E

Tilt angle of the roof: 45°

Azimuth of the roof: 15° East (from South)

Collector: VELUX, 5 pieces of Type: S08 (D2178)

Technical data of one collector according to the VELUX data sheet (5/9-2006):

Net weight:	37 kg
Gross area:	1.6 m ²
Net area:	1.35 m ²
Absorber area:	1.36 m ²
Liquid content:	1.3 ltr
Proofed pressure:	10 bar
Max. pressure:	6 bar
Stagnation temperature:	196 °C
Start efficiency:	0.79
First loss coefficient k_1 :	3.76 W/m ² K
Second loss coefficient k_2 :	0.0073 W/m ² K ²

(Based on net collector area)

Incident angle modifier k_{Θ} : 0.95 at 50° ($k_{\Theta} = 1 - \tan^a(\Theta / 2)$; a = 3.9)

Heat capacity: 7.4 kJ/m²K (2.06 Wh/m²K)

Collector loop pipes:

Stainless steel flexible pipe

Length forward pipe:	12 m
Length return pipe:	18 m
Inner diameter:	16.3 mm
Outer diameter:	21.8 mm
Insulation thickness:	13.0 mm
Heat conductivity:	0.04 W/mK
Liquid content:	0.14 ltr/m

Solar tank:

Produced by Metro Therm A/S

Nominal volume:	360 liter
Dimensions of cabinet:	595 x 600 x 1820 mm
Insulation:	Polyurethane (PUR) foam and vacuum panel
PUR-foam, heat conductivity:	0.024 W/mK
Vacuum panel, heat conductivity:	0.005 W/mK

In order to have an as large as possible tank volume within a 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 is again foamed into a 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 small, 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.

In chapter 0 for the cylindrical part of the tank the heat loss rates for different insulation qualities are investigated in detail. The calculations showed that for this tank prototype the heat loss rate will be the same as the heat loss rate of a standard tank with 500 mm diameter within a 60 x 60 cm cabinet with a minimum foam thickness of 50 mm. According to information from Metro Therm A/S this standard 300 liter tank has a heat loss coefficient of 2.9 W/K and an effective volume of 290 liter.

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

Test data according to the test certificate from Danish Gas Technology Centre which is an accredited test laboratory in Denmark:

Boiler efficiency (36/30, 7 kW):	107.8 %
Boiler efficiency (50/30, 5 kW):	100.4 %
Boiler efficiency (50/30, 24 kW):	104.0 %
Boiler efficiency (60/40, 24 kW):	101.4 %

Calculated annual net efficiency for:

Domestic hot water:	2,000 kWh/a
Space heating:	20,000 kWh/a
	7.5 kW at -10 °C ambient temperature
Traditional space heating system:	$T_{\text{forward}} = 76.5^{\circ}\text{C}$; $T_{\text{return}} = 57.9^{\circ}\text{C}$ at -10°C
Low temperature space heating system:	$T_{\text{forward}} = 60.0^{\circ}\text{C}$; $T_{\text{return}} = 46.1^{\circ}\text{C}$ at -10°C

Yearly net efficiency, traditional:	96.4 %
Yearly net efficiency, low temperature:	98.4 %

Controller:

Producer:	Lodam A/S
Type:	LMC200
	Free programmable microprocessor controller
	4 pieces are connected via RS485 bus system

Main data for one LMC200:

Temperature sensor:	4, NTC-sensor
Digital Input:	4
Analog Input:	1
Potential free relay, 230V:	7
Analog Output, 0-10V:	2

In Fig. 22 the prototype controller for the demonstration system is shown. The master controller on the left and three slaves which are connected via a RS485 Bus.

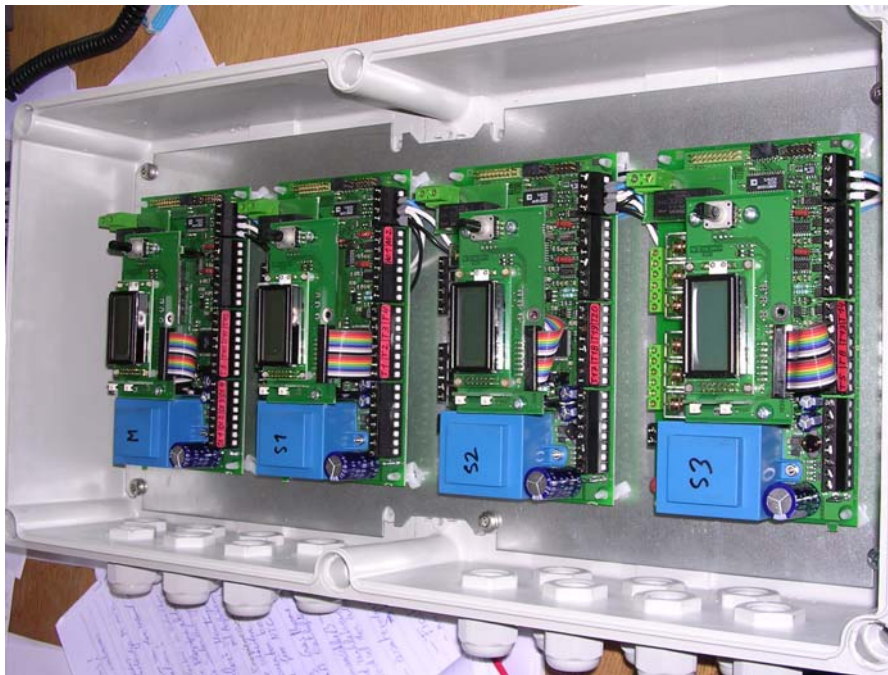


Fig. 22 Prototype controller; 4 LMC200 connected via RS485 Bus.

In Fig. 23 the hydraulic design is shown in detail. The hydraulic concept is exact like presented before in Fig.1. In this figure now the arrangement of the components and pipes fit as good as possible to reality, see Fig. 24 and also all components are shown which are installed in order to have a reliable operation of the system.

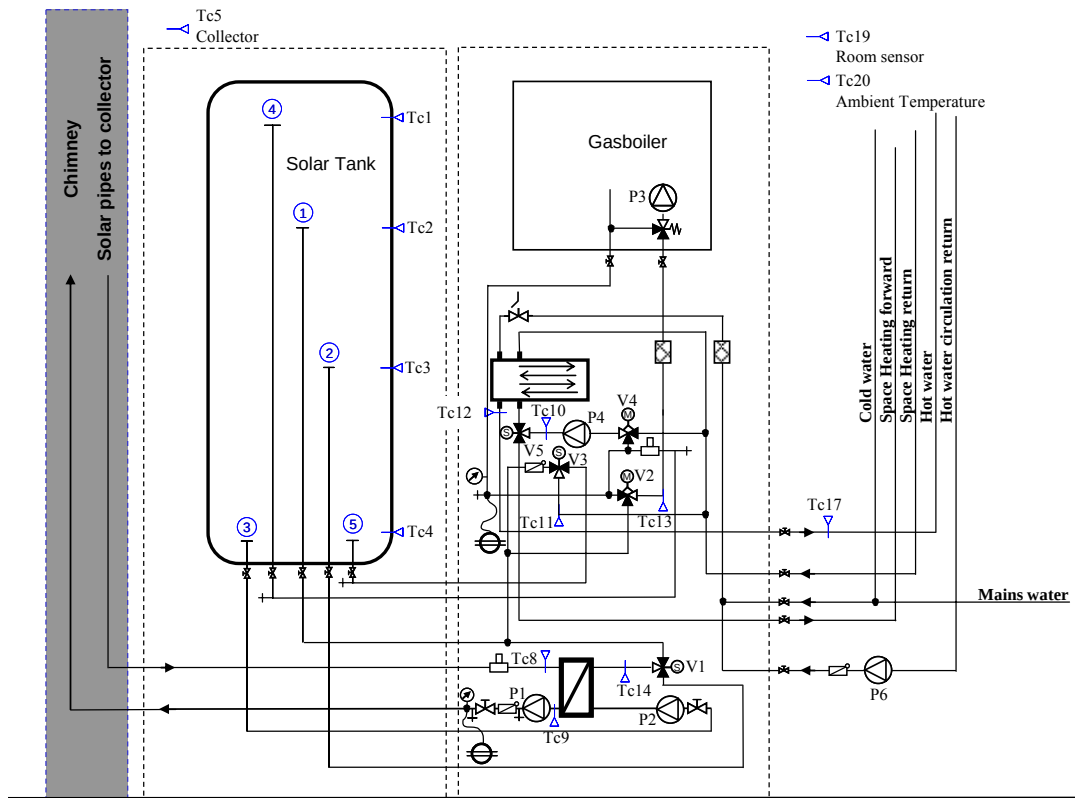


Fig. 23 Hydraulic scheme of the solar combisystem in the demonstration house in Helsingør/DK.



Fig. 24 Hydraulic unit inside the technical cabinet in the demonstration system; the big black box is the insulated domestic hot water heat exchanger, below the main pump P4 can be seen.

The installation of the demonstration system finally looks as shown in Fig. 25. On the wall left of the solar tank the prototype controller is mounted, further left the

black box is the frequency converter for speed controlling the pump P4. Above the frequency converter the main electric supply box is mounted, which includes the electric meter to measure the so called “parasitic” electricity to run the heating system.



Fig. 25 Installation after set in operation on 22/6-2006 (left) and after closing the cabinets with the cover plates (right).

Measurements of the old heating system

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 m ³	2973 Kd
5/5-2002 till 28/4-2003:	2,693 m ³	3243 Kd
28/4-2003 till 10/5-2004:	2,927 m ³	3090 Kd
1/1-2005 till 31/12-2005:	2,355 m ³	3097 Kd

Heating degree days are calculated by daily summing up the difference of 17 minus the ambient temperature. This is done for all days if the daily average ambient temperature is lower than 17 °C.

During the measurement period of the old heating system all the floor heating loops in the basement of the house were not set in operation. The basement in fact was heated by the heat losses from the natural gas boiler, the hot water tank and all the not insulated pipes in the technical room.

Until 21/12-2004 the natural gas boiler was operating in a very bad way due to a break of the internal controller and bad installation of the ambient temperature sensor mounted outside at the house wall.

For domestic hot water preparation the boiler set temperature was constant at about 85°C. Even if there was no heat demand, the pump was on all the time and circulating water to the hot water tank heat exchanger. Much more worse was the fact that also the ventilator of the combustion air was also running all the time, even when the burner was switched off due to exceeding the maximum

temperature. Therefore the standby losses especially in summertime were extremely high.

Also the space heating controller was not able to operate in a proper way because (as found later when installing the new system) the ambient temperature sensor was mounted that bad, that there was no electrical contact. Therefore the controller could not measure the ambient temperature and as a logical consequence it was also not possible to heat the space heating forward temperature depending on the ambient temperature according to the chosen “heating curve”.

Due to this bad installation of the ambient temperature sensor the natural gas boiler was only able to use an internal fail case strategy which obviously was to heat the forward temperature to about 8-10 K higher temperature than the return flow temperature. Detailed investigations on this detail, e.g. by asking Vaillant, were not done.

Description of the measurement concept

In order to get the heat balance of the complete house, the following measurement concept, see Fig. 26 was designed and installed.

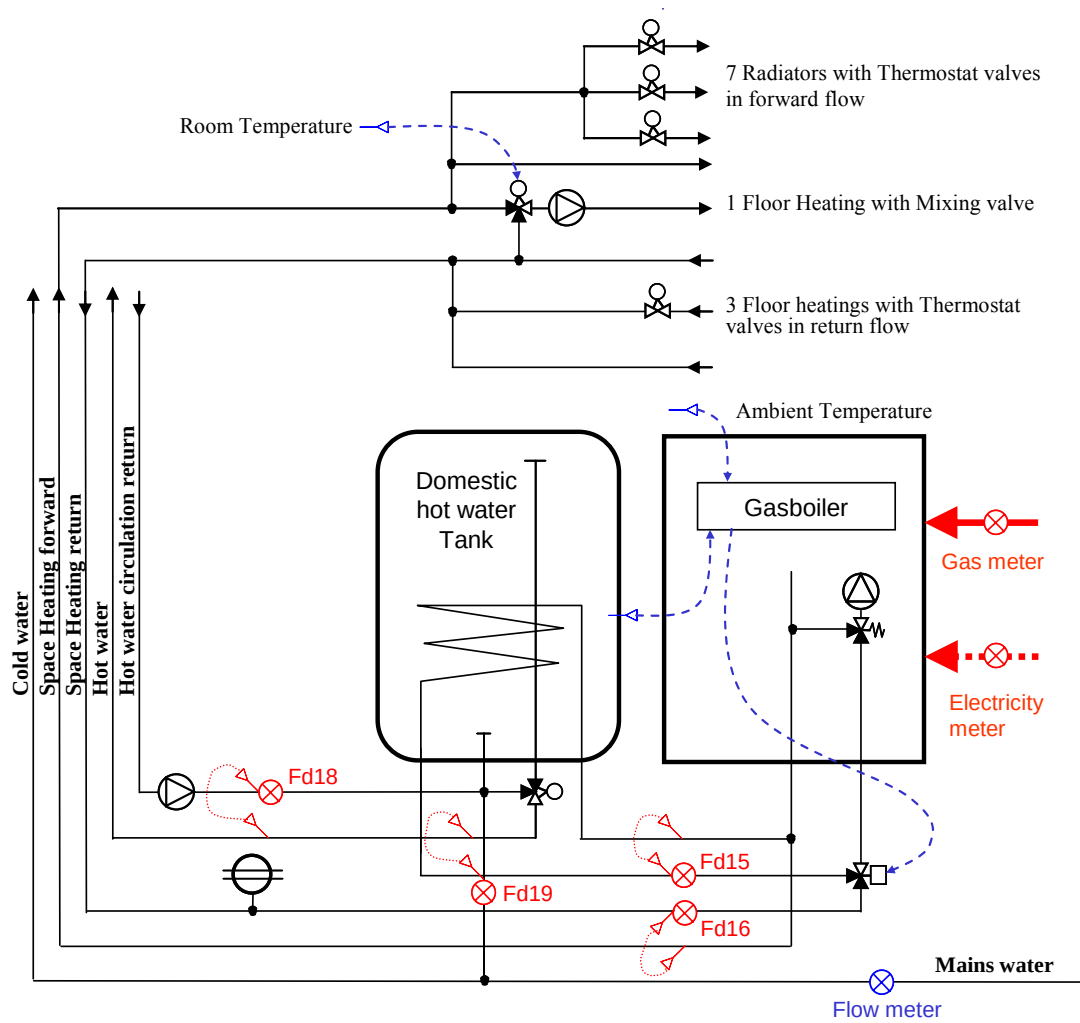


Fig. 26 Hydraulic scheme and measurement concept for the old heating system.

In total four energy meter, one natural gas meter and one electricity meter were used:

1. Fd15: "Domestic Hot Water-Heating"
Energy meter for measuring the heat that is produced by the boiler and used for heating the hot water tank.
2. Fd16: "Space Heating"
Energy meter for measuring the heat that is produced by the boiler and used for space heating.
3. Fd18: "Domestic Hot Water-Circulation"
Energy meter for measuring the domestic hot water circulation heat losses.
4. Fd19: "Domestic Hot Water-Consumption"
Energy meter for measuring the domestic hot water consumption.
5. Gas meter: "Natural Gas Consumption"
Measuring the natural gas consumption in $[m^3]$ that is used by the non condensing natural gas boiler.
6. Electric meter: "Electricity"
Measuring the electricity consumption to run the heating system: This is the boiler itself including the internal circulation pump and the controller plus the floor heating circulation pump and the domestic hot water circulation pump.

All these meters were equipped with pulse outputs for specified quantities of energy or volume per pulse, which were connected to a datalogger. Additional to the temperature sensors of the energy meters, at the same positions thermocouples were mounted and connected to the datalogger as well. All these data were collected and saved in the memory of the datalogger in periods of five minutes.

The datalogger used, was a DATATAKER DT50.

The four energy meter were from the former Danish company CLORIUS:
Type: CLORIUS Combimeter 3 EPD in combination with PT100 temperature sensors

According to the data sheet the accuracy of this type of energy meter is:

±4%: if: $Q > 0.3 \text{ m}^3/\text{h}$ and: temperature difference $> 20 \text{ K}$

±6%: if: $Q < 0.3 \text{ m}^3/\text{h}$ and: temperature difference $> 20 \text{ K}$

±6%: if: $Q > 0.3 \text{ m}^3/\text{h}$ and: temperature difference $< 10 \text{ K}$

±8%: if: $Q < 0.3 \text{ m}^3/\text{h}$ and: temperature difference $< 10 \text{ K}$

±5%: if: $Q > 0.3 \text{ m}^3/\text{h}$ and: $10 \text{ K} < \text{temperature difference} < 20 \text{ K}$

±7%: if: $Q < 0.3 \text{ m}^3/\text{h}$ and: $10 \text{ K} < \text{temperature difference} < 20 \text{ K}$

Since the energy meters were quite old they were calibrated. Calibration was done relative against each other but not against a calibrated normal because such a normal was not available at that time. The calibration was done two times for the following conditions:

Flow rate: $0.4 \text{ m}^3/\text{h}$ Temperature: $32 \text{ }^\circ\text{C} / 15 \text{ }^\circ\text{C}$ Power: 8 kW

Flow rate: $0.5 \text{ m}^3/\text{h}$ Temperature: $50 \text{ }^\circ\text{C} / 16 \text{ }^\circ\text{C}$ Power: 20 kW

The result of the calibration was that all four energy meters measured within the range of $\pm 2\%$ of the average in both tests. It was assumed that therefore also the absolute level of the measurements should be clear within the accuracy stated in the data sheet.

The gas meter was a standard gas meter from the natural gas utility. It was an IGA, type: AC-5M. This gas meter was temperature calibrated to a reference temperature of $15.6 \text{ }^\circ\text{C}$. According to the information from the natural gas utility the pressure of the natural gas typically is constant 22 mbar above ambient pressure. The accuracy of this gas meter according to the data sheet was:

±2%: if: $Q > 0.05 \text{ m}^3/\text{h}$

±3%: if: $0.025 < Q < 0.05 \text{ m}^3/\text{h}$

The electricity meter was from the Danish company TEE A/S: LK Type Wh3163, Class 2, therefore the accuracy of this electricity meter is $\pm 2 \%$.

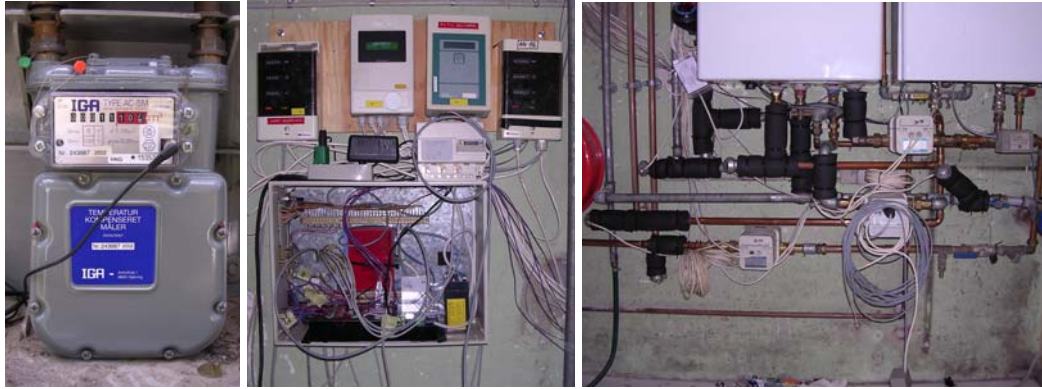


Fig. 27 Measurement equipment for the old heating system: left picture shows the gas meter, the middle picture the box with the datalogger DT50 and the electricity meter and the electronic modules of the energy meters above and the right picture the flow meters and the temperature sensors below the boiler and the hot water tank.

Energy balance of the old heating system

In the demonstration house the old heating system based on a non condensing natural gas boiler was measured for a period of 21 months from August 2004 till April 2006. First, two points need to be explained in order to understand the graphs and tables:

- Conversion of measured cubic meter natural gas to energy:
To convert the natural gas consumption, which is measured in the gas meter in cubic meter to energy, the following heating value was used:

Low heating value: 10.67 kWh/m^3 ($= 11.02 \text{ kWh/m}_n^3$)

This is the average value of 42 measurement points in Denmark for the twelve months from April 2005 until March 2006. The maximum difference over these 12 months and all 42 measurement points was $\pm 0.5\%$ of this chosen value. Due to this very small variation, it was decided to use one constant value for the complete evaluation in the old heating system.

It has to be noted, that all graphs and tables are based on the low heating value of the natural gas.

- The efficiencies which are presented are defined as:

1. Boiler Efficiency:

$$\eta_{\text{boil}} = \frac{\text{Domestic Hot Water Heating} + \text{Space Heating}}{\text{Natural Gas Consumption}} \quad \text{Eq. 1}$$

2. Natural Gas - COP:

$$\text{COP} = \frac{\text{Domestic Hot Water Consumption} + \text{Space Heating}}{\text{Natural Gas Consumption}} \quad \text{Eq. 2}$$

3. Domestic Hot Water Efficiency:

$$\eta_{\text{DHW}} = \frac{\text{Domestic Hot Water Consumption}}{\text{Domestic Hot Water Heating}} \quad \text{Eq. 3}$$

4. Hydraulic Efficiency:

$$\eta_{\text{hyd}} = \frac{\text{Domestic Hot Water Consumption} + \text{Space Heating}}{\text{Domestic Hot Water Heating} + \text{Space Heating}} \quad \text{Eq. 4}$$

“Boiler Efficiency” is the average efficiency of the boiler over a period and therefore including start/stop losses and standby losses.

“Natural Gas - COP” is the coefficient of performance based on the natural gas consumption that is calculated with the low heating value.

“Domestic Hot Water Efficiency” is not including the boiler efficiency, therefore it is an efficiency taking into account the heat losses of the hot water tank, the pipes between the hot water tank and the boiler and the hot water circulation losses. To calculate the COP_{DHW} only for hot water preparation, this is only possible for months, if no space heating energy is measured:

$$\text{COP}_{\text{DHW}} = \eta_{\text{DHW}} * \eta_{\text{boil}} = \frac{\text{Domestic Hot Water Consumption}}{\text{Natural Gas Consumption}} \quad \text{Eq. 5}$$

If this equation is used for months including space heating energy, it is important to have in mind that the boiler efficiency is an average value for the whole month and therefore strongly influenced by the boiler efficiency during space heating, which typically is much higher than the boiler efficiency during hot water preparation.

“Hydraulic Efficiency” is showing the overall system efficiency excluding the boiler efficiency. This key figure mainly will be used later to compare the new system with the old system without the influence of the different boilers.

Until 21/12-2004 the controller of the boiler had a break and therefore the system was operating very inefficient. This can be observed in figure 26 especially from August until December 2004, where all three efficiencies are dramatically low. Also the energy demand for “Domestic Hot Water-Heating” is abnormal high compared to “Domestic Hot Water-Consumption”, about 2.5 times higher. After reparation on 21/12-2004 the results are much better. On 21/12-2004 three main problems were solved:

1. The internal heat exchanger was exchanged because the old one was leaking.
2. The controller was repaired in such a way that if the burner was switched off, also the internal pump and the combustion air ventilator was switched off.
3. The controller also was repaired in such a way that during space heating the forward temperature was not the same as for hot water preparation, which was 85 °C.

Due to the fact that the ambient temperature sensor had no contact to the controller, the space heating forward temperature still was not according to the set heating curve.

The summer months July and August 2005 show the very typical decrease of the efficiencies if (almost) only hot water preparation demand has to be supplied.

On 21/11-2005 the hot water circulation pump was set in operation by the electrician. The pump was controlled by a clock and was in operation daily from 6 to 10 a.m. and 17 to 20 p.m. On 20/12-2005 the house owner decided to switch off the hot water circulation pump because of the huge heat losses. As the numbers in table 2 show, the heat losses of 297 kWh during 30 days are in same order as the hot water consumption. In other words the hot water circulation losses were about 100% of the hot water consumption, and this just based on 7 operating hours per day. The reasons for this high circulation losses are explained in the next chapter more detailed.

Looking on the tendency of “Domestic Hot Water Efficiency” from January 2005 until April 2006 it can be observed that this efficiency is decreasing from around 80% to less than 70%. This tendency fits to the also occurring reduction of the hot water consumption in the same period, what therefore is assumed to be the explanation.

In the months May, June and September, October 2005 the boiler efficiency is about 5 per cent points higher than in the core heating period. This is most likely due to the lower temperature level of the space heating system and the higher combustion air temperature during this period which both is reducing the exhaust gas losses. Again most likely this is also influenced by the fact that the ambient temperature sensor was not connected to the boiler controller.

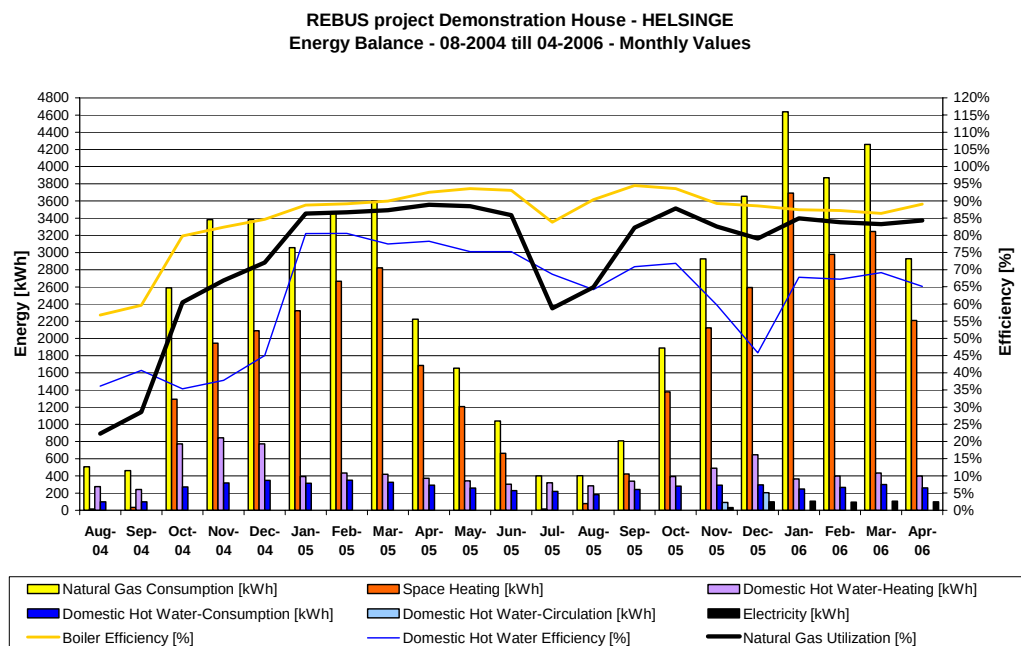


Figure 28. Energy balance for the old heating system in the demonstration house.

Table 2 Energy data for the old heating system in the demonstration house

	Ambient Temperature Source: DMI	Natural Gas Consumption Low Heating Value = 10.67 kWh/m ³	Space Heating	Space Heating	Space Heating Temperature Difference Monthly average	Domestic Hot Water-Heating	Domestic Hot Water-Consumption	Domestic Hot Water-Consumption	Domestic Hot Water Consumption Temperature Difference Monthly average	Domestic Hot Water-Circulation (21/11-05 till 20/12-05; daily 6-10 and 17-20)	Electricity Heating System (from 21/11-05)	Boiler Efficiency (Boiler/Gas)	Domestic Hot Water Efficiency	Natural Gas - COP (DHW+SH)/(Gas) Circulation as Loss	Hydraulic Efficiency (DHW+SH)/(Boiler+Solar) Circulation as Loss
		Gas	SH				DHW			Circ					
	[°C]	[kWh]	[kWh]	[m ³]	[K]	[kWh]	[kWh]	[m ³]	[K]	[kWh]	[kWh]	[%]	[%]	[%]	[%]
Aug.04	17.7	507	14	1.1	10.9	274	99	1.5	58.1	0	-	56.8%	36.1%	22.3%	39.2%
Sep.04	13.5	460	33	1.7	17.0	241	98	1.4	60.3	0	-	59.6%	40.7%	28.6%	47.9%
Okt.04	9.4	2588	1292	30.7	36.3	773	273	3.9	60.3	0	-	79.8%	35.3%	60.5%	75.8%
Nov.04	4.7	3382	1943	43.8	38.2	844	319	4.4	62.5	0	-	82.4%	37.8%	66.9%	81.2%
Dez.04	3.3	3382	2090	120.6	14.9	773	348	5.0	60.5	0	-	84.6%	45.0%	72.1%	85.2%
Jän.05	2.6	3055	2322	243.8	8.2	391	315	4.9	55.8	0	-	88.8%	80.5%	86.3%	97.2%
Feb.05	-0.3	3477	2665	223.8	10.3	434	350	5.3	57.1	0	-	89.1%	80.6%	86.7%	97.3%
Mär.05	0.9	3602	2822	234.0	10.4	418	324	4.9	57.0	0	-	89.9%	77.5%	87.3%	97.1%
Apr.05	7.8	2224	1685	218.8	6.6	373	292	4.6	54.6	0	-	92.5%	78.3%	88.9%	96.1%
Mai.05	11.0	1655	1207	182.1	5.7	342	257	4.2	52.6	0	-	93.6%	75.2%	88.5%	94.5%
Jun.05	14.1	1038	663	90.2	6.3	304	229	3.9	50.6	0	-	93.1%	75.2%	85.9%	92.2%
Jul.05	17.2	400	15	0.9	13.8	320	220	3.9	48.1	0	-	83.8%	68.7%	58.8%	70.1%
Aug.05	15.2	401	77	16.5	4.0	285	183	5.2	30.3	0	-	90.4%	64.2%	64.9%	71.8%
Sep.05	13.9	808	424	105.9	3.4	340	241	3.8	54.5	0	-	94.5%	70.9%	82.3%	87.0%
Okt.05	10.3	1890	1378	227.1	5.2	391	281	4.3	57.0	0	-	93.6%	71.8%	87.8%	93.8%
Nov.05	5.2	2926	2124	258.0	7.1	489	292	4.3	59.2	91	31	89.3%	59.7%	82.6%	92.5%
Dez.05	1.9	3654	2593	218.5	10.2	644	295	4.3	59.4	206	98	88.6%	45.8%	79.0%	89.2%
2005		25131	17974	2019.6	7.7	4733	3279	53.5	52.8	-	-	90.4%	69.3%	84.6%	93.6%
Jän.06	-1.6	4639	3693	283.2	11.2	364	247	3.6	59.6	0	106	87.4%	67.8%	84.9%	97.1%
Feb.06	-0.2	3871	2978	255.0	10.1	397	267	3.7	61.9	0	94	87.2%	67.2%	83.8%	96.1%
Mär.06	-1.1	4257	3243	258.7	10.8	434	300	4.1	62.6	0	104	86.4%	69.1%	83.2%	96.4%
Apr.06	5.9	2928	2210	273.2	7.0	398	259	3.6	61.5	0	98	89.1%	65.1%	84.3%	94.7%
Mai.06															

Specific detailed evaluation of the old heating system

Based on some graphs taken from the quite big amount of measured data, some main characteristics of the old heating system are discussed in the following part. First in figure 29 the behaviour of the old heating system is shown in its worst manner before the big reparation on 21/12-2004. It should be mentioned that this way of operation was, according to the house owners, the standard for many years. Even when to the maintenance technician it was reported that it seems that something is wrong with the heating system, nothing was found.

First it can be observed that the inlet- and outlet temperatures of the hot water heat exchanger (“Domestic Hot Water – Forward” and the “Domestic Hot Water – Return” temperature) most of the time are at the same temperature level of about 85°C. Also the flow rate “Domestic Hot Water – heating” is always very high: 500 to 750 liter/h. This clearly shows that hot water heating is on all the time and therefore pipe losses and boiler losses are high because of this high temperature level the system is kept all the time. An additional effect which can not be seen in the figure is the fact that also the ventilator for the combustion air was running all the time, even if the burner of the boiler was off. Of course this caused also huge stand by losses of the boiler.

The “Space Heating – Forward” temperature also has always this high temperature level of 85°C. The “Space Heating – Return” temperature corresponds quite well with the flow rate “Space Heating”. Each time when

obviously a radiator valve was opened, the space heating return temperature drops to about the room temperature for a while before it is rising again.

To get a stable comfort temperature in the house with such a heating system obviously is not possible. It was also reported by the inhabitants that it was always too hot or too cold. Of course also the inhabitants did not use the thermostat valves correctly. They used them more or less as on and off valves turning always from totally open to closed and backwards.

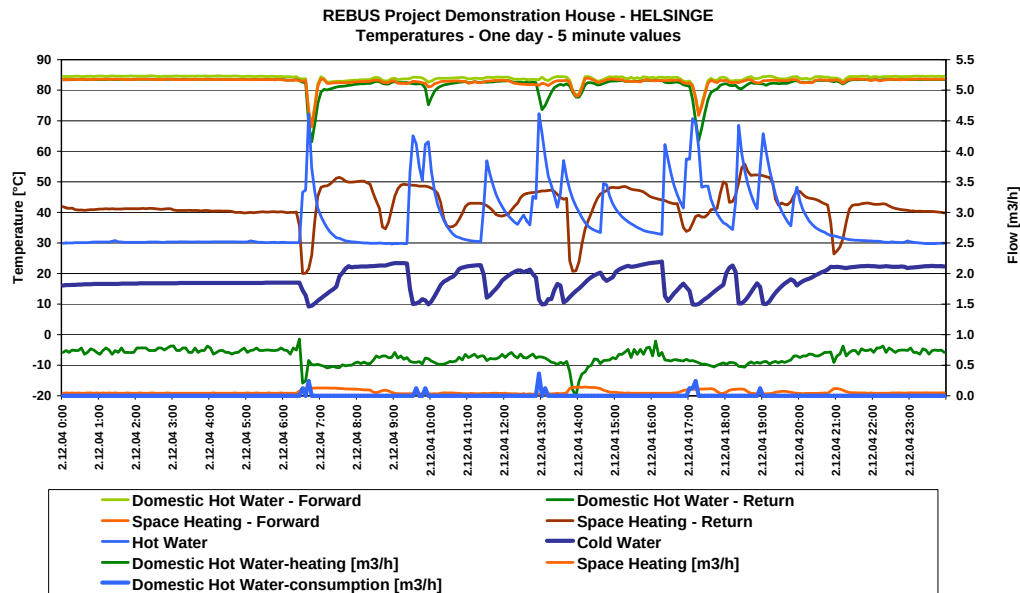


Figure 29 Behaviour of the old heating system before reparation on 21/12-2004

In figure 30 the old heating system behaviour after reparation is shown. Now the system is changing between the two different operating modes of hot water preparation and space heating.

When heating the hot water tank, the temperature “Domestic Hot Water – Forward” still reaches about 85°C and the temperature “Domestic Hot Water – Return” is about 10 K lower and the flow rate “Domestic Hot Water – heating” reaches about 0.75 m³/h. This is a very typical situation in such conventional heating systems, which do not allow a condensing natural gas boiler to operate with the benefit of condensing since the return temperature is much higher than the dew point of about 57 °C. With a flow rate of 0.75 m³/h and a temperature difference of 10 K the power can be calculated to about 9 kW. Since the gas boiler is able to produce much more power, it is clear that the heat exchanger is designed too small.

It is a question why natural gas boilers are designed, built and sold, which have a peak power for hot water preparation up to 30 kW, if they never can deliver this power?

Of course in this system the hot water set temperature is about 70 °C, which is very high. But even if the set temperature for hot water would be 60 °C (what is typical to avoid legionella problems in the hot water tank), it would be necessary to have a forward temperature of at least 15 K more, therefore 75°C. Since the temperature difference will be about the same, the return temperature can be expected to be around 65 °C, still much too high for condensing.

Further on it can be observed that almost after each hot water tapping, the boiler starts to heat the hot water tank. This also can be observed in the most conventional heating systems. The reason is that only one temperature sensor in combination with a hysteresis is used to switch on and off the boiler. Therefore the often mentioned argument that a hot water tank is avoiding many starts and stops, in reality is not true for most of the heating systems.

Looking on the behaviour of the system during space heating now a much lower “Space Heating – Forward” temperature can be observed. Due to the fact that the ambient temperature sensor had no electrical contact to the boiler controller, the boiler could not control the forward temperature depending on the ambient temperature according to the heating curve. Obviously the boiler controller had an internal fail case strategy heating the forward temperature to about 8 K more than the return temperature. In figure 30 it can be seen that depending on the flow rate “Space Heating” the “Space Heating – Return” temperature was reacting and the “Space Heating – Forward” temperature is following with a more or less constant temperature difference.

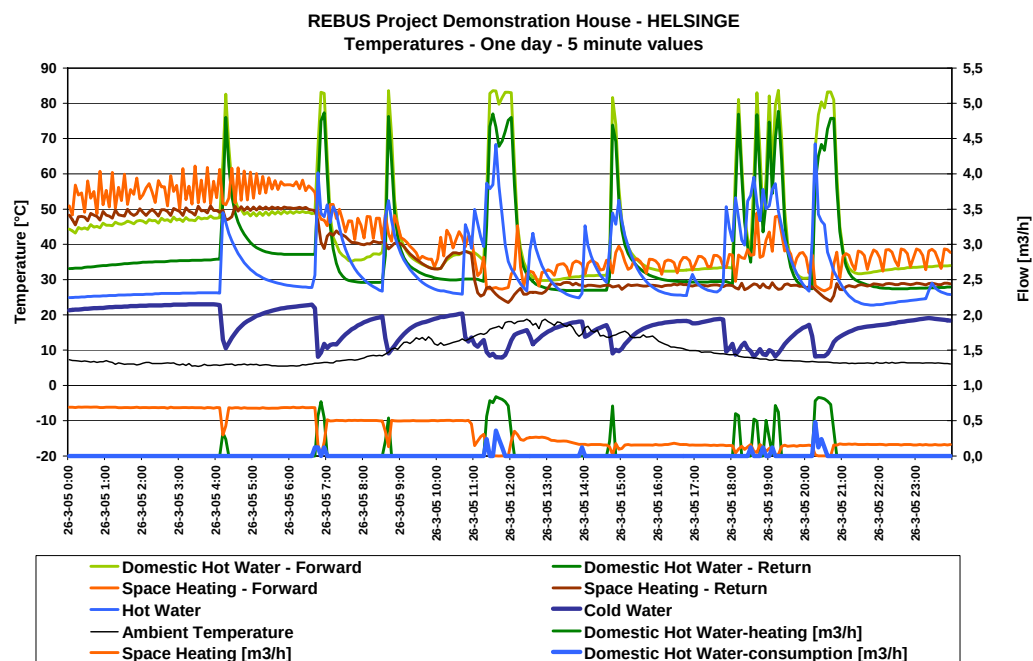


Figure 30 Behaviour of the old heating system after reparation on 21/12-2004

In figure 31 a day during the one month period with active hot water circulation pump is shown. Based on the evolution of the “Water Circulation Return” temperature it can be observed that the circulation pump is switched on at 6 a.m. and 5 p.m. when the temperature is increasing with a step upwards. The circulation pump stops at 10 a.m. and 8 p.m. respectively, therefore the total running time per day is 7 hours. This is the case for all seven days a week.

Looking on the energy “Circulation Losses” and the high “Water Circulation Return” and “Hot Water” temperature during the periods when the circulation pump is switched off, it can be observed that due to thermal driven buoyancy effects still a quite high flow rate occurs. The reason for that is a not working non return valve.

The effect of this mistake can also be observed during hot water tapping. For example at 1 p.m. during a hot water tapping the circulation return temperature drops down to less than 20 °C. This only can happen if cold water flows backwards through the circulation return pipe and this is only possible if there is no non return valve. Of course this results also in much lower tap temperature because high temperature from the normal hot water pipe is mixed with cold water from the circulation pipe. This effect also was reported from the inhabitants.

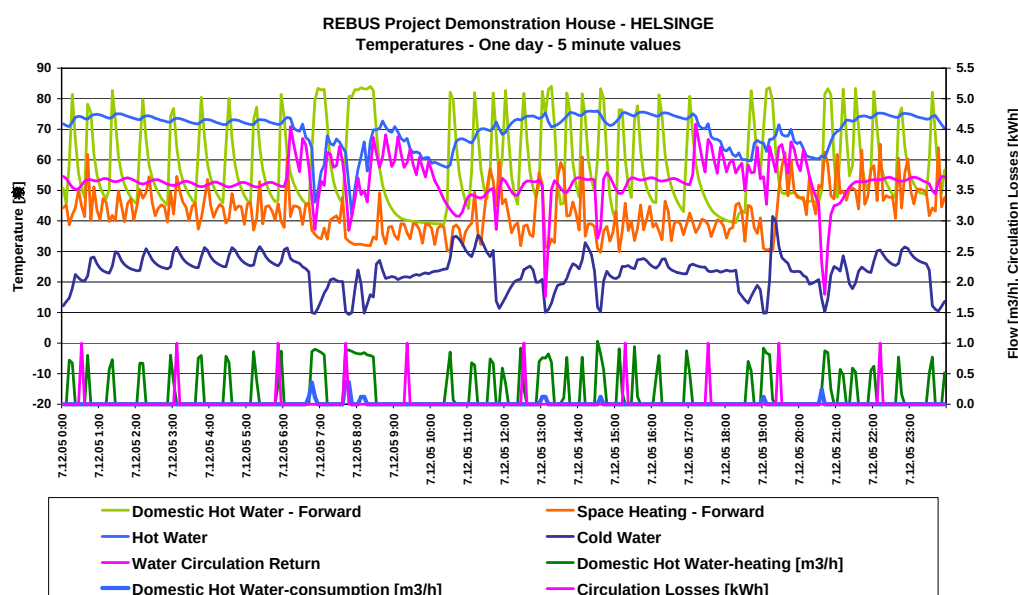


Figure 31 Behaviour of the old heating system when the hot water circulation pump was activated.

Measurements of the new solar combisystem

In June 2006 the new solar combisystem was installed and set in operation on 20/6-2006. On 6/7-2006 the collector loop was filled and set in operation as well. Unfortunately, the old energy meters, which were used again, after reinstallation, did not operate properly anymore. Therefore, it was necessary to order new energy meters. Due to holiday period the delivery time was incredible long, the new energy meters were finally installed on 7/9-2006.

During the summer period 20/6 until 7/9-2006 only the gas meter, the electricity meter and one of the old, but reliable energy meter could be used.

The space heating forward temperature during this period was controlled by a heating curve depending on the ambient temperature with some special settings. The space heating forward temperature is 45 °C at ambient temperatures higher than 10 °C, 47 °C at ambient temperature of 0 °C and 60 °C at ambient temperature less than minus 10 °C, see figure 32. The main reasons for this setting are:

1. The space heating loop shall be operated as good as possible as a low flow system to ensure low return temperatures. Especially in autumn and spring, this is important to have a low temperature level in the solar tank to maximise the potential of gaining solar energy from the solar collector

loop. In combination with correct used and adjusted thermostat valves at the radiators the flow rates of each radiator are controlled automatically in such a way that a high temperature difference can be achieved.

2. In combination with other parameter settings in the controller, with this heating curve until an ambient temperature of 0 °C the condensing natural gas boiler is operating in the space heating mode with a forward temperature of about 52 °C, which ensures good condensation and therefore high boiler efficiency. At ambient temperatures less than 0 °C the gas boiler is operating in the domestic hot water mode with a forward temperature of about 62 °C, which is reducing the condensation rate significantly if the return temperature is not very low.

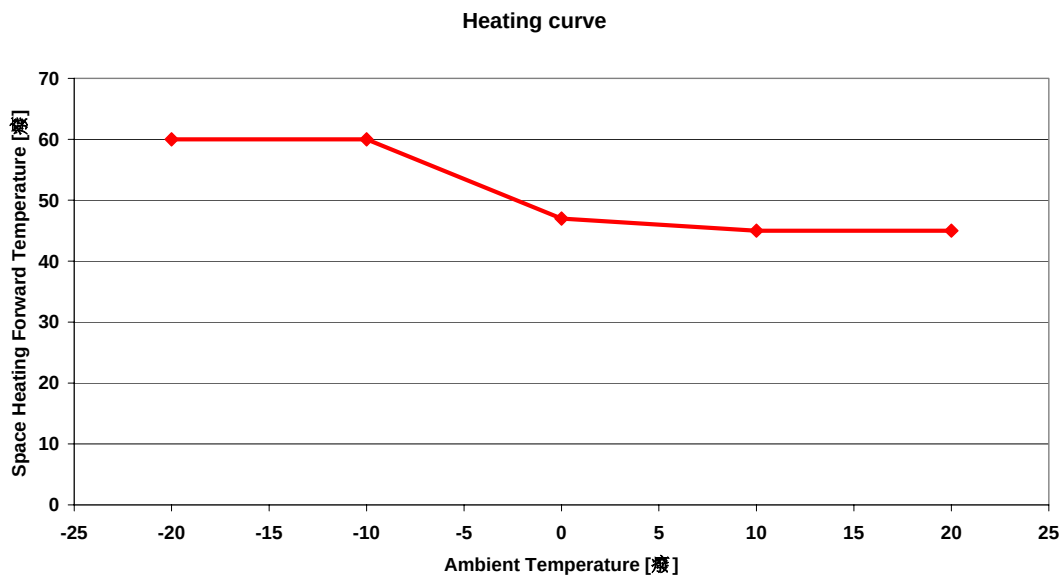


Figure 32 Heating curve for the space heating forward temperature depending on the ambient temperature.

Description of the measurement concept

In order to get the heat balance of the complete house, in total five energy meter, one natural gas meter and one electricity meter were installed, see figure 33:

1. Fd1: “Solar Gain”
Energy meter for measuring the heat that is delivered from the solar collector and used for heating the solar tank. This heat value is the collector gain minus heat losses of the primary solar loop and the solar heat exchanger.
2. Fd2: “Boiler”
Energy meter for measuring the heat that is produced by the boiler and delivered to the tank or directly used for space heating or hot water preparation.
3. Fd3: “Space Heating”
Energy meter for measuring the heat used for space heating.
4. Fd4: “Domestic Hot Water-Consumption”
Energy meter for measuring the domestic hot water consumption.
5. Fd5: “Domestic Hot Water-Circulation”
Energy meter for measuring the domestic hot water circulation heat losses.

6. Gas meter: “Natural Gas Consumption”
Measuring the natural gas consumption in [m³] that is used by the condensing natural gas boiler.
7. Electric meter: “Electricity”
Measuring the electricity consumption to run the solar combisystem: this is the boiler itself including the internal pump and the controller plus all three pumps and all five valves inside the technical unit, the floor heating circulation pump and the domestic hot water circulation pump.

In figure 33 the hydraulic scheme including the energy meter is shown. All temperature sensors shown in this figure and named with “Tc...” are connected to the controller.

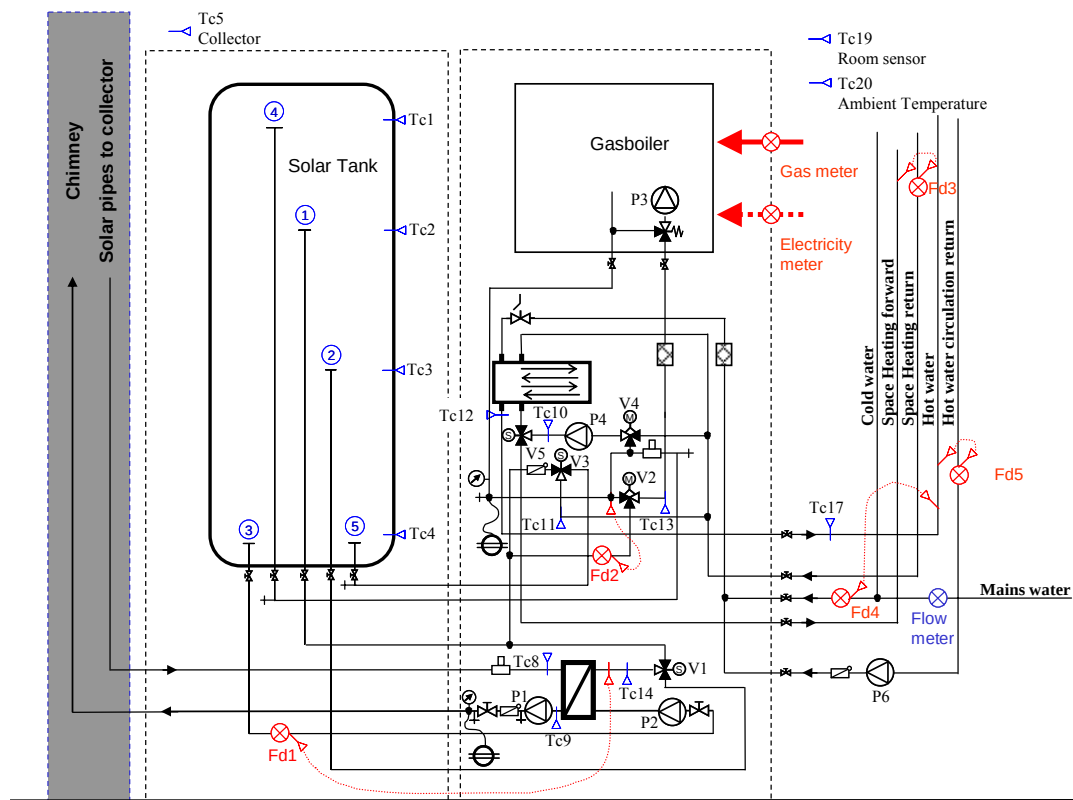


Figure 33 Hydraulic scheme and measurement concept for the new solar combisystem in the demonstration house.

All meters were equipped with pulse outputs for specified quantities of energy or volume per pulse, which were connected to a datalogger. Additional to the temperature sensors of the energy meters, at the same positions thermocouples were mounted and connected to the datalogger as well. All these data were collected and saved in the memory of the datalogger in periods of three minutes.

The datalogger used, was a DATATAKER DT500.

The five energy meters finally used were from the company Brunata A/S:

Type: HGQ3-R0-184 /1/B/0/-/24/0% 2 pieces

Type: HGQ3-R2-184 /1/B/0/-/24/0% 3 pieces

Accuracy according to EN 1434: class 2 (which corresponds to an accuracy of 2%)

The gas meter was a standard gas meter from the natural gas utility. It was the same gas meter as used for the measurements of the old heating system. It was an IGA, type: AC-5M. This gas meter was temperature calibrated to a reference temperature of 15.6 °C. According to the information from the natural gas utility the pressure of the natural gas typically is constant 22 mbar above ambient pressure. The accuracy of this gas meter according to the data sheet was:

$$\begin{aligned} \pm 2\%: & \text{ if: } Q > 0.05 \text{ m}^3/\text{h} \\ \pm 3\%: & \text{ if: } 0.025 < Q < 0.05 \text{ m}^3/\text{h} \end{aligned}$$

The electricity meter was from the Danish company TEE A/S: LK Type Wh3163, Class 2, therefore the accuracy of this electricity meter is $\pm 2\%$. It was the same electricity meter as used for the measurements of the old heating system.

The picture in figure 34 shows the measurement equipment mounted in the demonstration house.



Figure 34 Measurement equipment for the new solar combisystem; in the grey box the datalogger DT500; on the right, four of the energy meter are mounted on the wall.

Energy balance of the new solar combisystem

In the demonstration house the new solar heating system based on a condensing natural gas boiler was measured for a period of 3 months from October 2006 till December 2006. The monthly energy balance for this system is presented in

figure 35 and table 3. It is planned to collect the data further on till end of 2007 in order to get a full year. The efficiencies are defined as:

1. Boiler Efficiency:

$$\eta_{\text{boil}} = \frac{\text{Boiler}}{\text{Natural Gas Consumption}} \quad \text{Eq. 6}$$

2. Solar Fraction:

$$\text{SF} = \frac{\text{Solar}}{\text{Solar} + \text{Boiler}} \quad \text{Eq. 7}$$

3. Natural Gas - COP:

$$\text{COP} = \frac{\text{Domestic Hot Water Consumption} + \text{Space Heating}}{\text{Natural Gas Consumption}} \quad \text{Eq. 8}$$

4. Hydraulic Efficiency:

$$\eta_{\text{hyd}} = \frac{\text{Domestic Hot Water Consumption} + \text{Space Heating}}{\text{Boiler} + \text{Solar}} \quad \text{Eq. 9}$$

“Boiler Efficiency” is the average efficiency of the boiler over a period and therefore including start/stop losses and standby losses.

“Solar Fraction” shows the share of energy delivered from the solar collector compared to the energy produced by the boiler (not the fuel consumption!).

“Natural Gas - COP” is the coefficient of performance based on the natural gas consumption that is calculated with the low heating value. In the case of solar heating systems, the COP can be much greater than one, because of the gained solar energy. In summer time, typically the COP is infinite thanks to 100 % solar fraction.

“Hydraulic Efficiency” shows how much of the energy delivered from boiler and solar collector was really consumed in the house. The remaining energy is heat loss.

The result of the few months is presented in figure 35 and table 3. In the period from October until middle of December in several steps, the controller program was evaluated, tested and improved. In addition, the technical unit was improved as well. On the other hand, the climate and the user behaviour are changing the boundary conditions daily. Therefore, several effects influence the key numbers in a positive or negative way and it is not possible to conclude based on monthly values how much the changes in the system improved the system.

REBUS project Demonstration House - HELSINGE
Energy Balance - 10-2006 till 12-2007 - Monthly Values

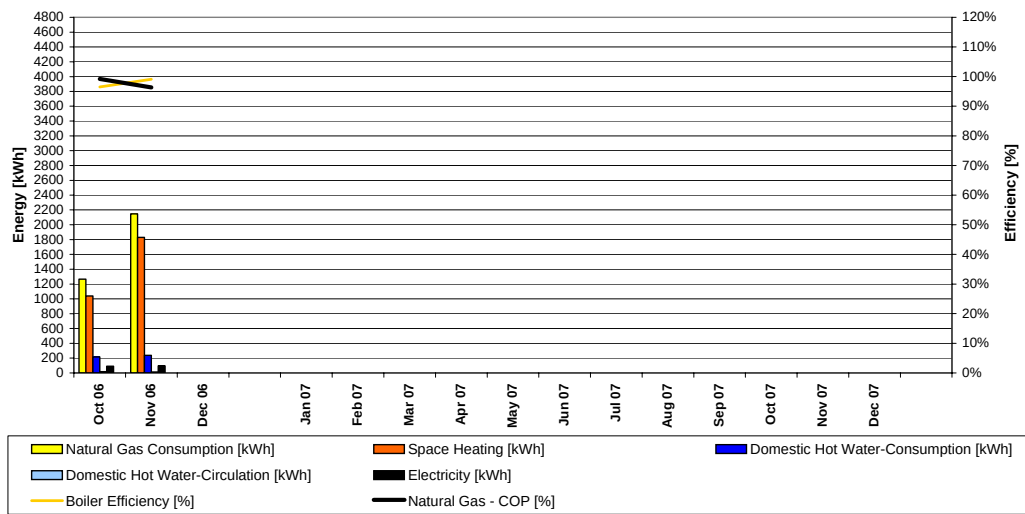


Figure 35 Energy balance for the new solar heating system in the demonstration house.

Table 3 Energy data for the new solar heating system in the demonstration house

	Ambient Temperature Source: DMI	Natural Gas Consumption Low Heating Value = 10.67 kWh/m ³	Boiler	Solar Gain	Space Heating	Space Heating Temperature Difference Monthly average	Domestic Hot Water-Consumption	Domestic Hot Water-Consumption Temperature Difference Monthly average	Domestic Hot Water-Circulation	Electricity Solar Heating System	Boiler Efficiency (Boiler/Gas)	Natural Gas - COP (DHW+SH)/(Gas)	Solar Fraction (Solar)/(Solar+Boiler)	Hydraulic Efficiency (DHW+SH)/(Boiler+Solar) Circulation as Loss
	[°C]	[kWh]	[kWh]	[kWh]	[kWh]	[m ³]	[K]	[kWh]	[m ³]	[K]	[kWh]	[%]	[%]	[%]
Okt.06	11.7	1266	1222	143	1040	75.31	11.9	216	5.27	35.3	18	91	96.5%	99.2%
Nov.06	7.4	2146	2127	66	1830	124.54	12.7	238	5.49	37.4	14	94	99.1%	96.4%
Dez.06														

Specific detailed evaluation of the new solar combisystem

In the following section based on data logged from the controller in the demonstration house some typical operating conditions are presented and discussed. The most important topic in this system is the domestic hot water preparation under all the different boundary conditions. Further, also the behaviour during space heating will be discussed based on some graphs. The following list gives an overview of the following graphs:

- System behaviour during summer time without space heating demand; stratification in the solar tank and hot water preparation;
- System behaviour during space heating period with effect of the auxiliary volume on the start/stop frequency of the natural gas boiler.
- Domestic hot water preparation during space heating season with different start and operating conditions.

In figure 36 a typical summer situation is shown. The solar tank is heated to about 65°C by the solar collector (Tc8) before the solar pump (Pc2) is switched off at

about 16:30. After some hot water tapplings (DI1) in the evening the bottom of the tank (Tc4) has a temperature of about 32°C. During the night due to the internal heat transfer in the solar tank the bottom is heated to about 36°C, whereas the upper part of the tank is getting colder (Tc1-Tc3) due to heat losses and heat transfer to lower parts of the tank. In the morning, several hot water tapplings (DI1) take place and obviously only little sunshine enables the system to preheat the bottom part of the tank again.

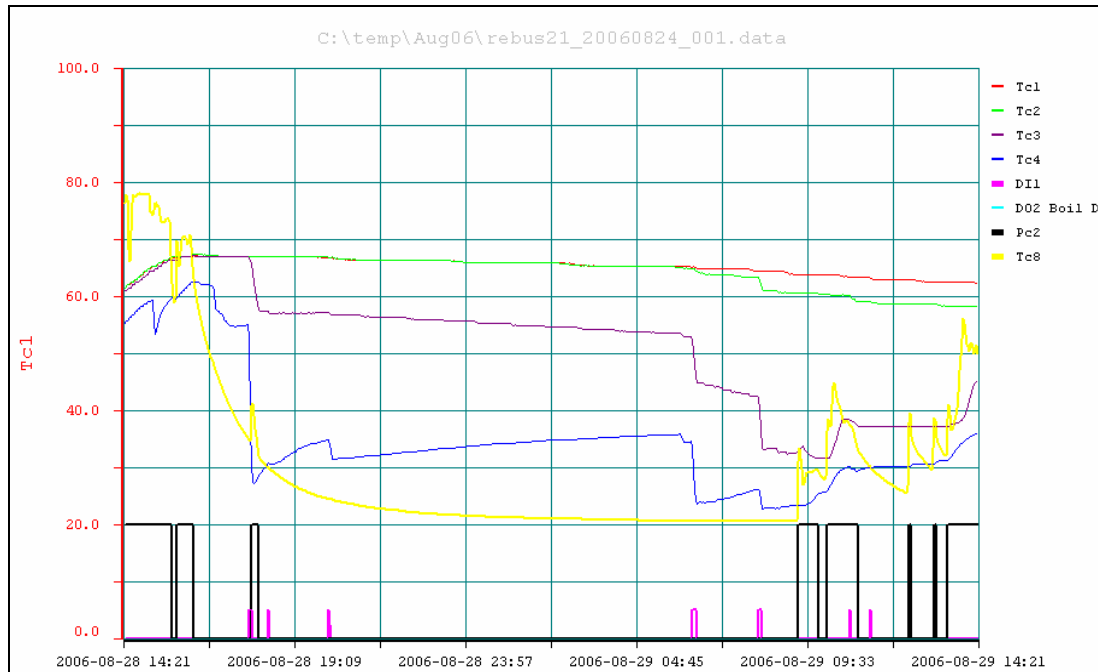


Figure 36 Stratification in the solar tank on a summer day with hot water preparation and without auxiliary heat demand.

In figure 37 a day is shown where due to sufficient high solar energy the solar tank reaches the maximum temperature of 90°C at about 14:00. At that time, the pump (Pc2) is switched off and the solar collector temperature (Tc5) very fast increases until stagnation temperature is reached. The stagnation temperature is more than 150°C, just the controller is not able to measure temperatures more than 150°C. As long as the solar collector temperature is more than the maximum temperature (in this case 100°C), the pumps (Pc1 and Pc2) are not allowed to run. As soon as the collector temperature decreases to less than 100°C the pumps start again at about 17:30. Since at that time the incident angle is very small, the collector is not able any more to produce heat at the desired temperature level of about 60°C.

After the hot water tapplings in the evening the bottom temperature (Tc4) during night increased by about 15K from about 27 to 42°C due to internal heat transfer. In the morning, the solar collector pumps (Pc2) in the beginning are running only for short intervalls until the irradiation is powerfull enough. During this time it can be observed that the temperature sensor (Tc3) is strongly decreasing. This is due to some hot water tapping but also because the flow entering the tank via pipe 2 is much colder than the water in the tank. It can be observed that when (Tc8) is getting higher than (Tc3), of course (Tc3) is increasing again quite fast.

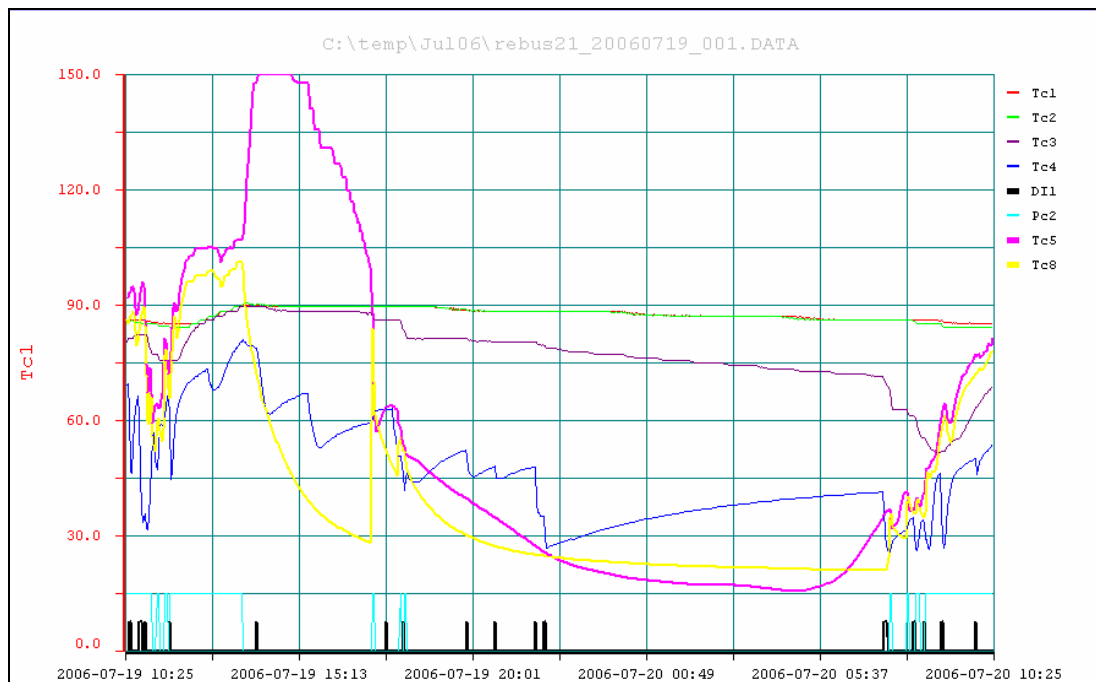


Figure 37 Stratification in the solar tank on a summer day with high irradiation which is leading to stagnation of the solar collector.

In figure 38 a summer day is shown where the temperature at the top of the tank (Tc1) is not sufficient high anymore for domestic hot water preparation. At about 06:00 in the morning in parallel to hot water tapping also the natural gas boiler is in operation. The lower part of the solar tank (Tc3 and Tc4) is cooled and the top part of the solar tank (Tc1 and Tc2) is heated at the same time.

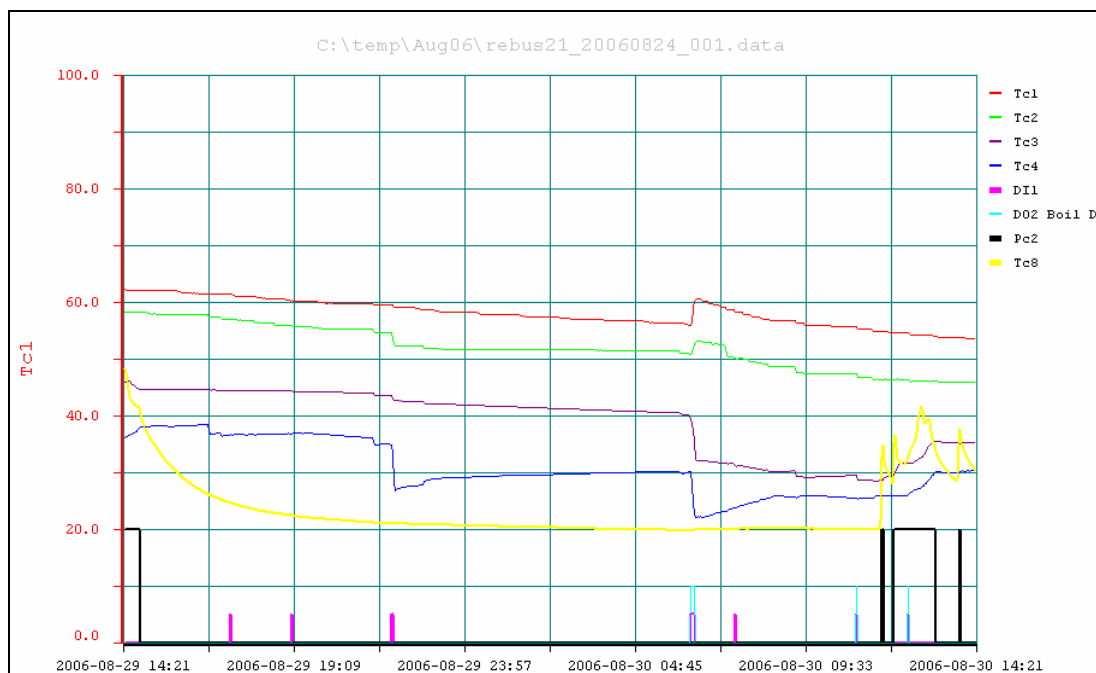


Figure 38 Stratification in the solar tank on a summer day with hot water preparation and with auxiliary heat demand.

In figure 39 the stratification in the solar tank in a night period of 12 hours during space heating period in November is shown. The ambient temperature sensor

(Tc20) measured about 10°C the whole night. The space heating forward temperature (Tc10) according to the heating curve was 45°C. The space heating return temperature (Tc11) was about 28°C, which shows that the thermostat valves at all radiators and floor heating loops were set correct. The space heating consumption during the period 23:18 until 06:30 was 14 kWh. This corresponds to an average space heating load of about 1.9 kW with a flow rate of about 95 ltr/h.

Within this period of 7.2 hours, the natural gas boiler started only 5 times (DO1) due to the space heating demand. The very short operation at about 23:30 was due to a short hot water tapping. Since the minimum power of the natural gas boiler is about 5.5 kW, in a typical standard installation (without using an auxiliary volume) the boiler would operate in a start/stop modus with a much higher start frequency of about 6 times per hour. Further, due to the internal bypass valve (increasing the internal flow rate from 95 to about 450 ltr/h) the internal return temperature would be about 47°C instead of less than 30°C as shown by (Tc2) in figure 39.

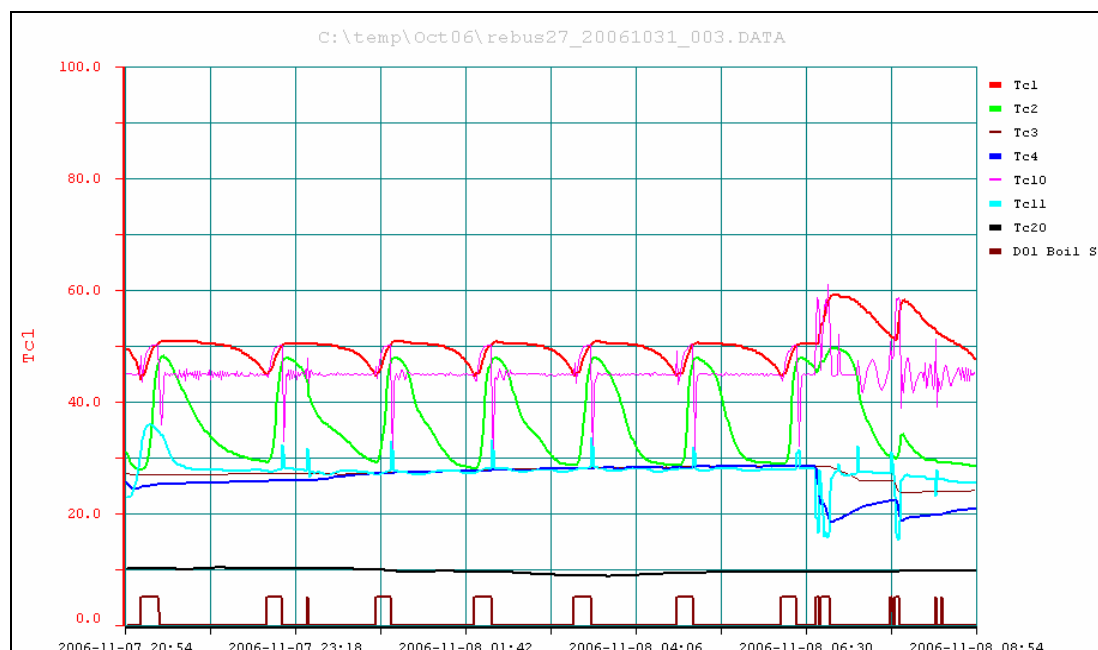


Figure 39 Start/Stop frequency of the natural gas boiler with low space heating return temperature.

The following graphs show the domestic hot water preparation in all cases during space heating period with different start and/or boundary conditions.

In figure 40 after the night the first hot water tapping is shown. Since the temperature in the top of the solar tank (Tc1) is not high enough the boiler is starting immediately (DO2). The hot water tap temperature (Tc12) is increasing very fast to about 43°C, slower to about 45°C and then faster again until the set temperature of 50°C is reached. The reason for this reduced increasing speed is that the boiler at that time still is in the internal heating up phase and not connected to the hot water heat exchanger. The valve V2 allows only internal flow in the boiler loop. When the boiler is able to produce high enough temperature the valve V2 opens and the forward temperature (Tc10) is increasing to about 56°C. Due to the opening of V2 the boiler needs to adapt the power which takes some time. This is the reason why the temperature (Tc10) decreases again a little before it reaches the constant temperature of about 59°C. The evolution of the tap

temperature (Tc12) shows after reaching the set temperature only very small oscillations anymore thanks to the fast speed control of the pump P4 (Pc4_speed).

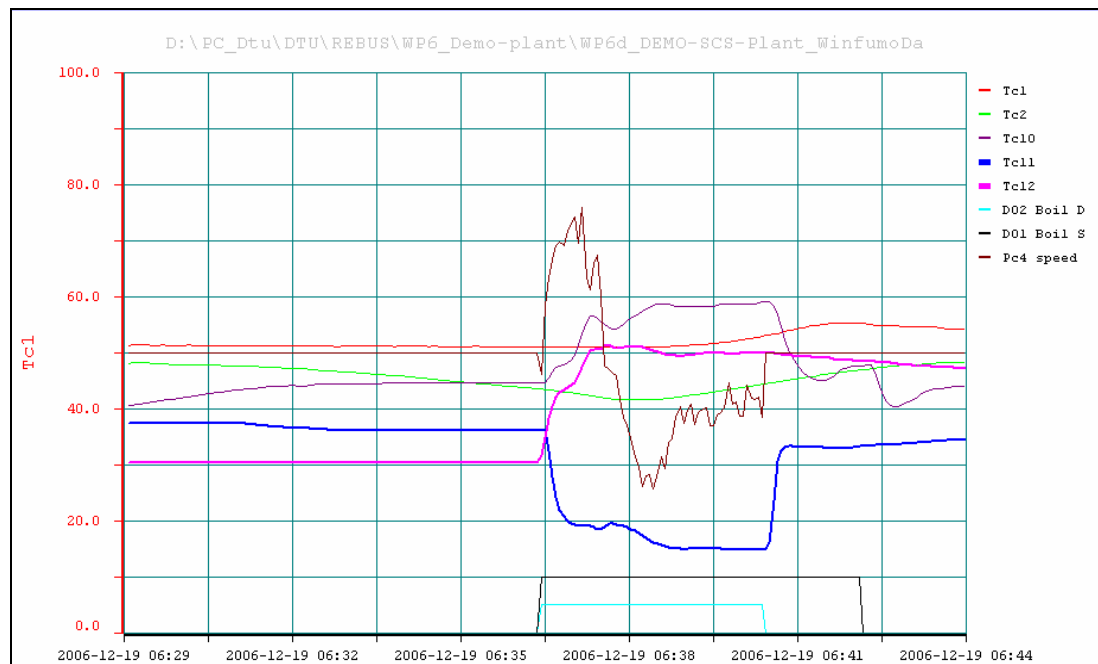


Figure 40 Domestic hot water preparation for a shower in the morning during space heating with boiler support from the beginning.

Figure 41 shows again a morning shower but with preheating with the hot water circulation pump and the function “circulation on demand”. At about 06:25 with a short tapping of just one second the circulation the hot water system and the pipes are heated until the temperature sensor (Tc17) reaches the switch off temperature of 40°C. The circulation pump is running about one minute. During this period it can be observed that the return temperature (Tc11) of course is at a relative high level since no cold water is tapped.

Some minutes later when the shower really starts the tap temperature (Tc12) immediately has about 50°C. Just due to the start procedure of the boiler the tap temperature for a short while decreases to about 45°C before it reaches the set temperature of 50°C again. During the shower, the temperature is kept exactly at 50°C. The return temperature (Tc11) during the shower which is going back to the solar tank has about 16°C where at that time the cold water temperature is about 10°C.

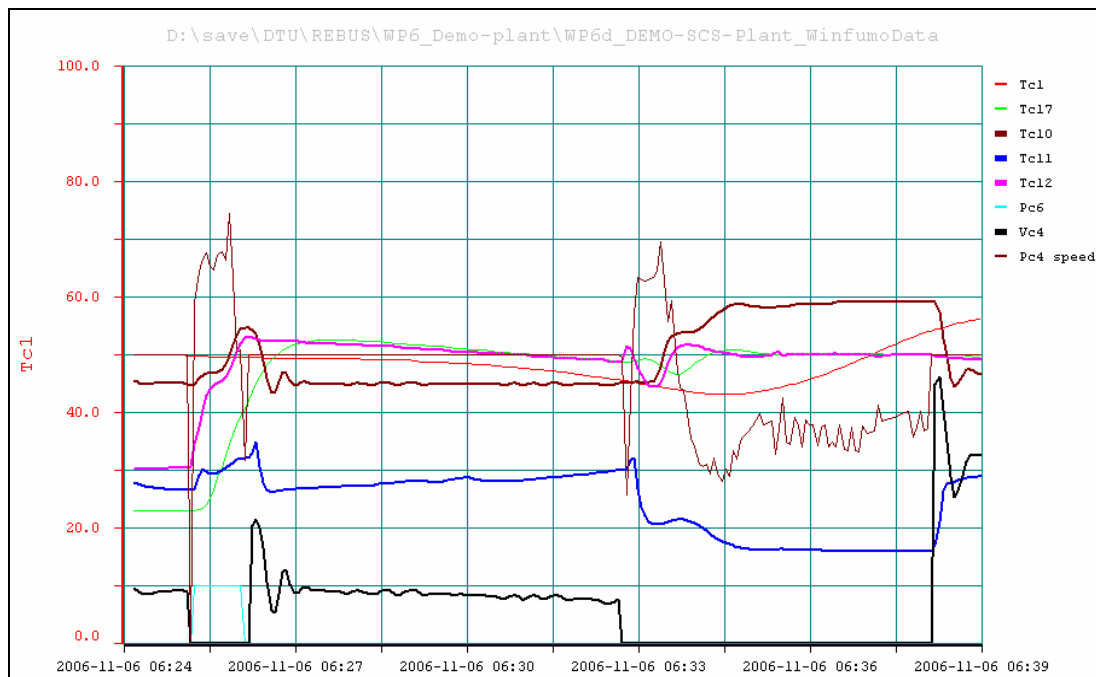


Figure 41 Domestic hot water preparation for a shower in the morning during space heating with boiler support from the beginning and preheating with circulation on demand.

In figure 42 a situation is shown where hot water tapping starts at about 19:13 with just sufficient high temperature (Tc1) in the solar tank. At about 19:14 the boiler has to start (DO2_Boil_D). Therefore, the forward temperature (Tc10) shows some oscillations before the boiler set temperature of about 59°C is reached. Due to the fast reacting PID controlled pump P4 (Pc4_speed) the oscillations of the tap temperature (Tc12) directly after the heat exchanger are much less, in fact less than $\pm 1.5\text{K}$. In practice after several meters of pipes this oscillations are damped much more that it is almost impossible to feel it.

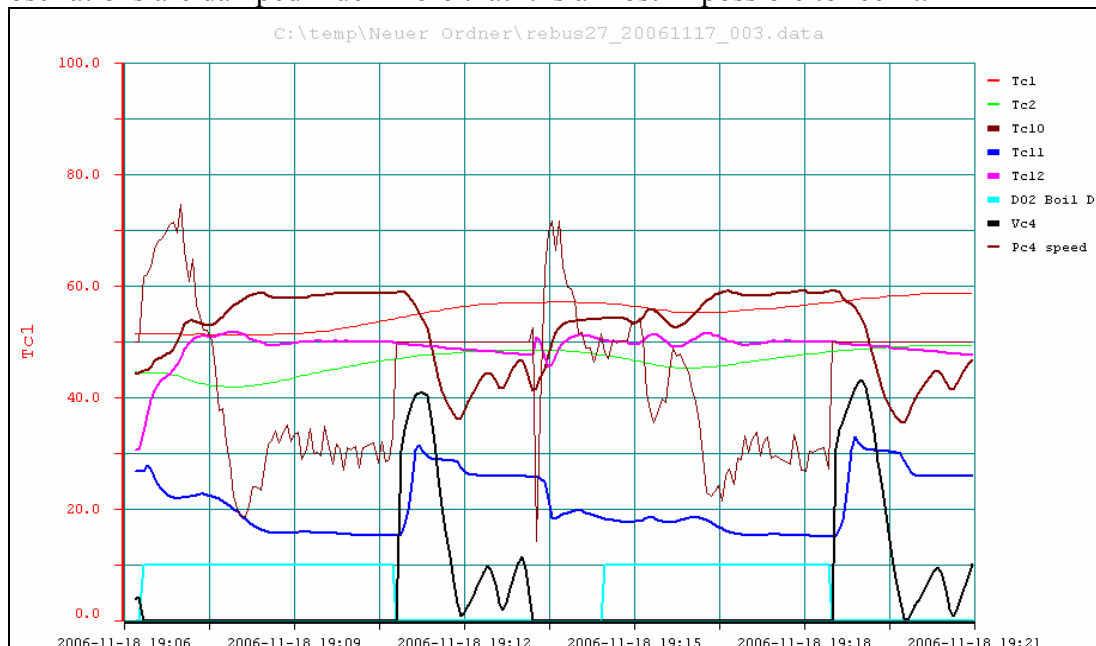


Figure 42 Domestic hot water preparation with boiler start during tapping.

The next example in figure 43 shows a hot water tapping with very low flow rate of about 3 ltr/min and the boiler in operation. In this situation even when the

pump speed (Pc4_speed) is set to zero the boiler pump would force a too high flow rate passing the hot water heat exchanger and resulting in too high tap temperature (Tc12). To avoid this problem the valve V2 is controlled that way, that partly the boiler forward flow is mixed to the boiler return flow and therefore reducing the pressure to the hot water heat exchanger. As a result the forward temperature (Tc10) which is produced by the boiler is oscillating quite strong, where the hot water temperature (Tc12) has much smaller amplitudes due to the fast speed controlled pump P4 (Pc4_speed). Due to this very low hot water flow rate of about 3 ltr/min it takes about one minute to pass three meter pipe length, which has a quite strong damping effect until the water reaches for example the shower.

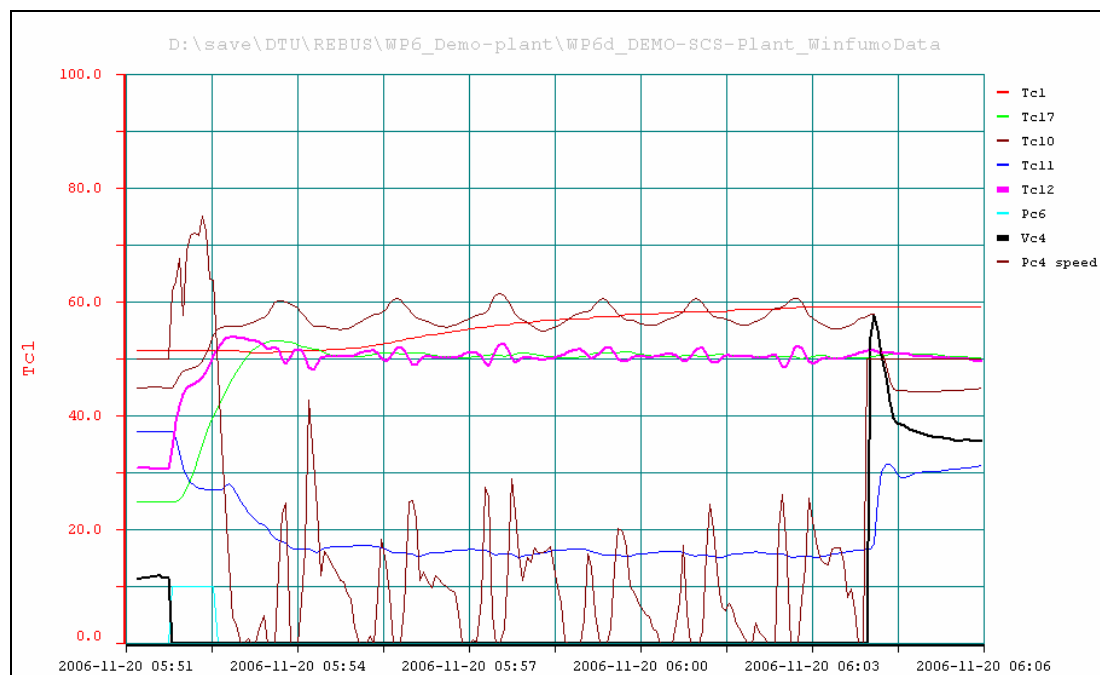


Figure 43 Domestic hot water preparation with very low flow rate with boiler support.

In figure 44 some hot water tapping is shown with strong changing of the tap flow rate. At 13:06 a short tapping of about 15 seconds takes place, followed by about one minute space heating (Vc4 is about 10%) and then again a long period of about six minutes hot water tapping. In this case in the start phase the tap temperature (Tc12) has oscillations with a relative large amplitude up to 56°C in the beginning. This happens because the boiler was initially very hot since it was for a short moment started (DO2_Boil_D) just before for this very short tapping. At 13:10 the system has reached constant operating conditions (Pc4_speed at about 20% and Tc10 at 59°C). At 13:11 suddenly the temperature (Tc12) is falling, obviously due to a strong increase of the hot water flow rate due to a second open tap somewhere in the house. The pump speed (Pc4_speed) immediately jumps from 20 to 60% to increase the heating power. As a result the temperature (Tc12) after a short peak down to about 47°C is quick and without oscillations increasing again to the set temperature of 50°C. At 13:12 the second tap obviously is closed again. The tap temperature (Tc12) again has a short peak up to 53°C and is reaching very quick without oscillations the set temperature of 50°C.

Since the power of the boiler during this hot water tapping was much higher than needed, the surplus power was used to heat up the auxiliary volume to a temperature (Tc1) of 59°C. Therefore the following hot water tapping at 13:15 was powered directly from the tank and the boiler did not need to start immediately.

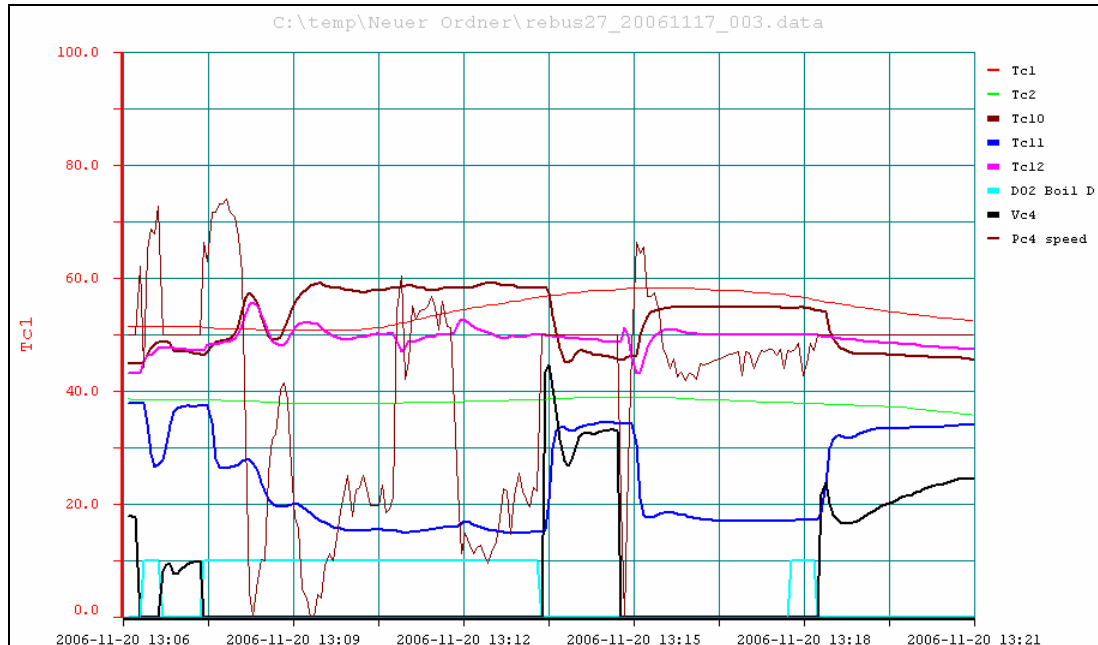


Figure 44 Domestic hot water preparation with boiler support and strong changing flow rates.

In figure 45 hot water tapping is shown again with large changes of the hot water flow rate but without boiler support since the temperature in the tank (Tc1) is high enough. Compared to Figure 44 it can be observed that the tap temperature (Tc12) has slightly higher peaks after the change of the flow rate. The reason for this effect most likely is, that in this case the pump P4 has no support from the boiler pump and that the forward temperature (Tc10) is only 57°C instead of 59°C before. But also in this case the tap temperature (Tc12) reaches very quick and without oscillations the set temperature of 50°C.

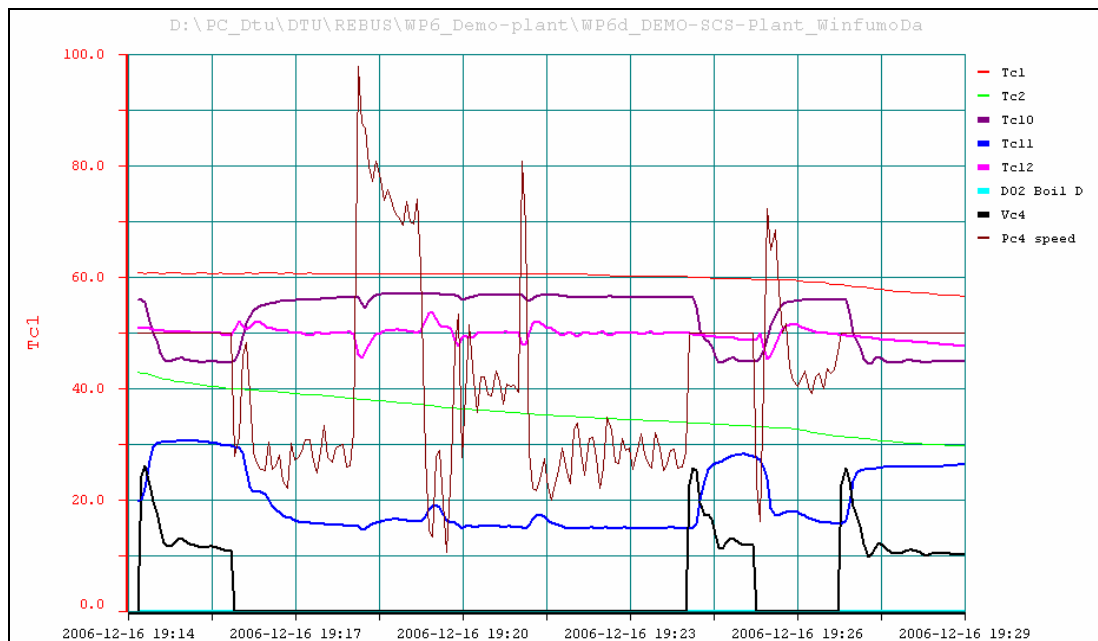


Figure 45 Domestic hot water preparation without boiler support and strong changing flow rates.

Appendix 2: Activities at SERC

Executive Summary

The pellet version of the REBUS system concept has been further developed at the Solar Energy Research Center SERC. The key development work has been the design of a compact hydraulic unit for the collector circuit, and the redesign of the technical unit for connection to an external water jacketed stove. A complete prototype, delivered by the industry partners was tested in the lab and then installed in July 2006 in a house in Borlänge (Sweden). The monitoring results show excellent performance during both summer and winter. A number of dissemination activities have been carried out during the short period, and these have aroused significant interest. The main industry partners are interested in going from the demonstration to the market introduction phase.

Development Work

Compact Hydraulic Unit for Collector Circuit

In the initial prototypes of the REBUS system that were tested in the lab, no solar circuit was made. This circuit was designed in the SCAS project, principally by SERC together with the industry partner Solentek AB. The circuit consists of the collector, connecting pipes and a hydraulic unit (see Figure B-1) that contains all other necessary components such as pump, heat exchanger, filter, one-way valves, flow metering points, temperature sensors and de-aeration unit. A novel feature of the circuit is the use of small diameter tubes and high pressure pump that gives a sufficiently high velocity in all parts of the circuit such that any gas bubbles in the fluid are carried along with the fluid and cannot collect in any part of the circuit other than the de-aeration unit. This means that there is no need for an air removal valve on the roof, a common cause of problems in other systems. The circuit also uses the partial evaporation technology which means that the fluid in the collector is forced back down into the expansion vessel if the temperature in the collector exceeds approx. 140°C, reducing the thermal load of the fluid and thus increasing its lifetime. Any collector designed for low flow and good properties for partial evaporation can be used in the design.

The circuit is sized for collector fields from 5 – 20 m².



Figure B-1: Compact hydraulic unit for collector circuit developed by SERC in collaboration with Solentek AB.

Technical Unit for System with Separate Water Jacketed Pellet Stove

Solentek AB have found during the course of the REBUS project that one of the main barriers to the REBUS concept is the lack of chimneys in the spaces

available for the system, such as utility room. This is due to the extra costs associated with installation of a new chimney. In many such houses, however, there is a chimney in the living room. Thus a system with a separate water jacketed stove is more attractive to such house owners than the system with integrated pellet burner. Hydraulically and for the controller, there is no difference to having the pellet burner integrated into the technical unit or to have it separated as a pellet stove, thus no changes in the system concept are necessary. However, the removal of the pellet boiler reduces the required space. This was utilised by exchanging the prototype rectangular standby water store for the auxiliary heater to a cylindrical one, a standard product of the industry partner Metro Therm A/S. A reduction in height was also possible.

Solar Store

The solar store was further developed by Metro Therm to have a slightly larger volume of 360 l, resulting in less space for the insulation. To compensate for this, vacuum insulation panels were used on the sides. The resulting heat loss coefficient measured at SERC was better than most store that have been tested at ITW, one of the main solar testing institutes in Europe (see Figure B-2). The test method used at SERC was not exactly the same, but the results should be comparable.

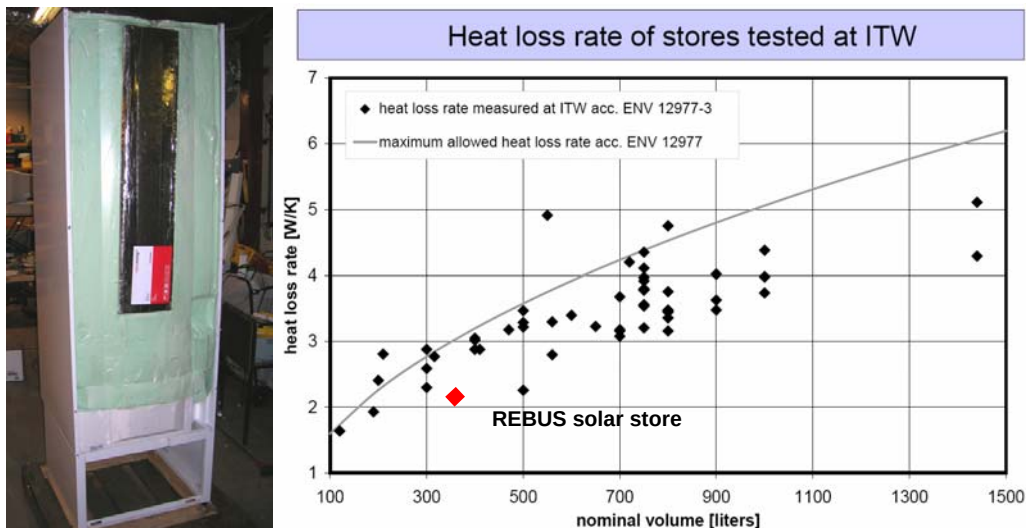


Figure B-2: (left) Solar tank with larger water volume enabled using thin vacuum insulation panels at on the sides and (right) heat loss coefficients of solar stores required by EU norms (ENV-12977) and values for stores measured by ITW, Univ. Stuttgart together with that measured by SERC for the REBUS store (red diamond).

Demonstration System

Demonstration Site

A number of different potential sites for the demonstration system were checked during 2005 and early 2006. At the start of the SCAS project the site was finalised. The house is owned by an employee of Solentek AB, who is an industry PhD student at SERC. The house was built around 1910 and has been refurbished a couple of times since then.

At the start of 2006 the house was heated by electric heater panels with an electrically heated store for the hot water. The owner was very interested in converting to a pellet and solar system due to the high heating costs with electricity. The house is quite typical for houses of that age, there being approximately 40.000 houses of this house type of the roughly 500.000 electrically heated houses in total. There is also a garage/workshop on the property that is also heated electrically. Before the installation of the system, approx. 23.000 kWh electricity was used in the houses 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 point a 6 kW electrical heater in the 80 litre standby store in the technical unit was used as auxiliary heater. The stove is situated in the middle of the living room and is fed manually by the owners (see Figure B-3, left). 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. This was possible with the chosen variant with separate pellet stove (see Figure B-3, middle). The collector field of 10 m² (Figure B-3, right) consists of four modules of Svesol premium AR with a standard rated output of 465 kWh in Stockholm at constant 50°C. It was placed on the main roof facing 40°E with a slope of 40°.



Figure B-3: The demonstration site in Borlänge, with (left) water jacketed stove, (middle) technical and store units in a cupboard under the stairs, and (right) view of the 10 m² collector array on the roof.

Monitoring Results

Monitoring started at the end of July 2006, thus 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 wood used was estimated by the user and the tiled stove was assumed to have an efficiency of 50%. The total energy content of the log wood, used in January and February, was only 348 kWh.

Figure B-4 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 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

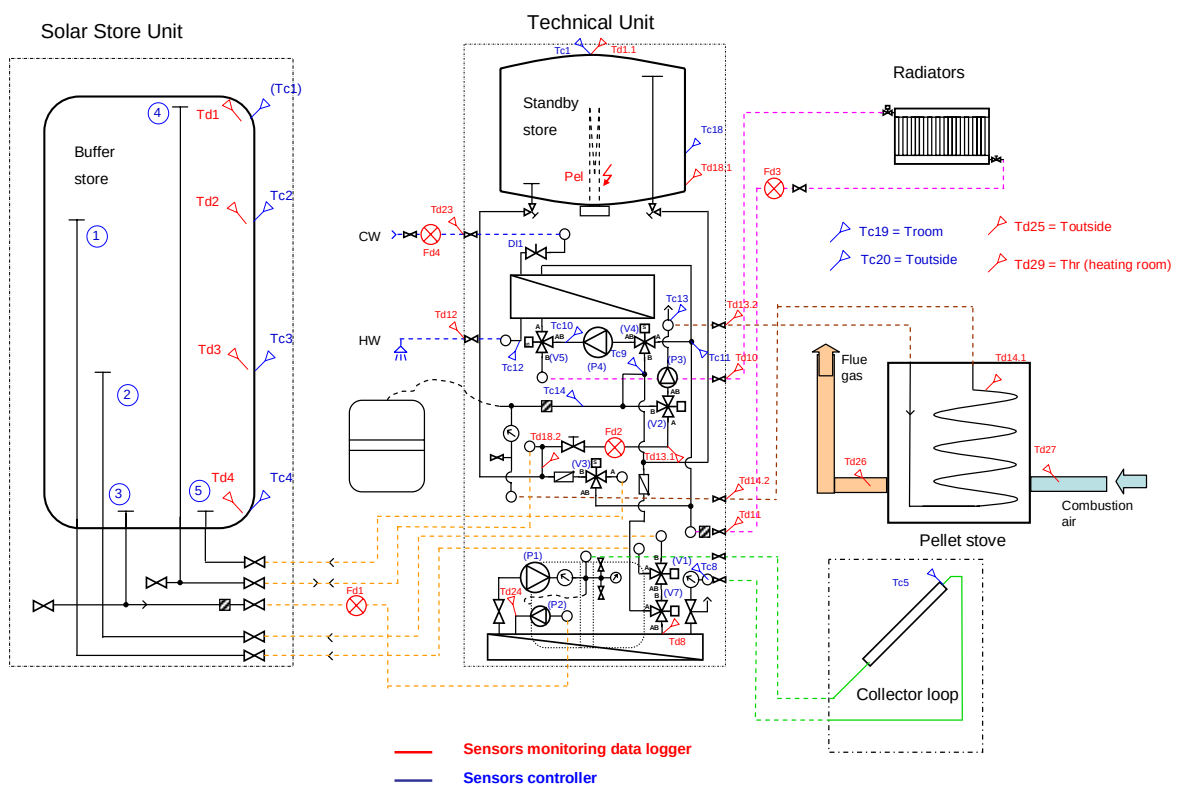


Figure B-4: REBUS system schematic with sensor positions for the REBUS controller (blue with subscript c) and the monitoring system (red with subscript d).

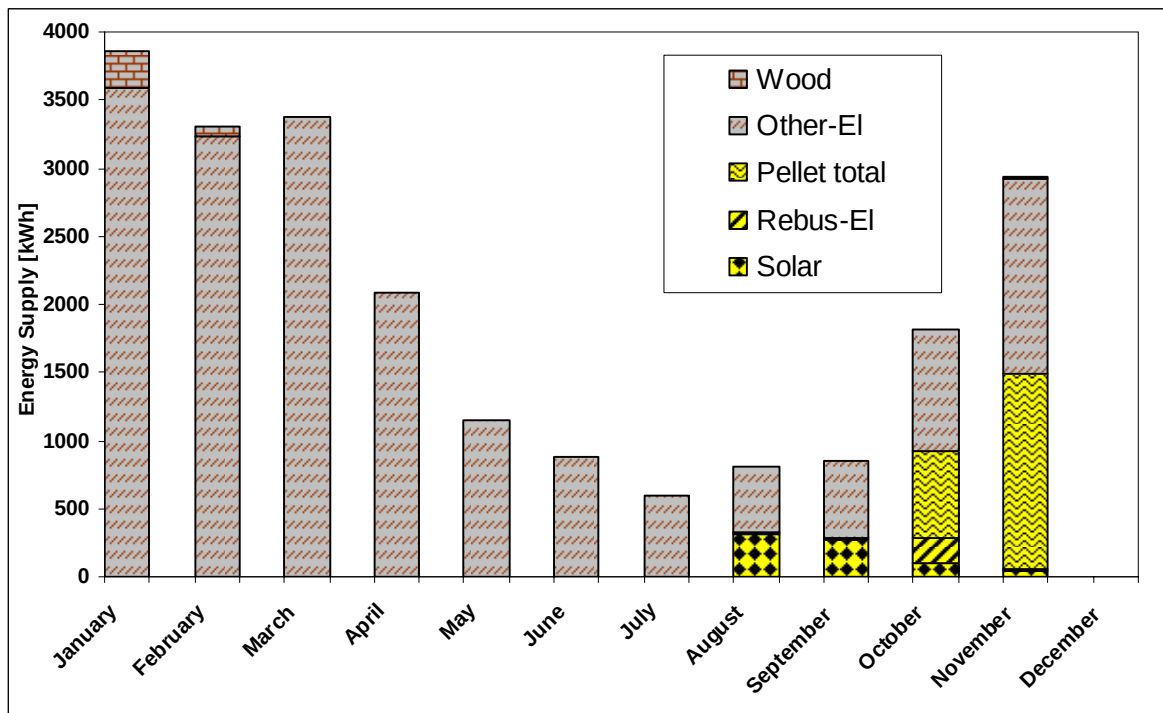


Figure B-5: Monthly energy supply during 2006 at the demonstration house. "Other-EI" is all electricity supply to the property except for the REBUS system. "REBUS-EI" is electricity supplied to the REBUS system including pumps, valves as well as electrical heating element.

Figure B-5 shows the monthly energy supply to the property, including heating of the garage, electricity for heating the car and other household electricity. The monitoring has coincided with a very mild autumn, with higher temperatures than normal. This is reflected in the lower energy supply figures. The electricity supply to the REBUS system was high for October as until the middle of October all auxiliary heat was supplied by electricity as the stove was not yet installed. In all other months, the REBUS system required very little electricity. Almost no auxiliary heat was required during August and September (see more details later).

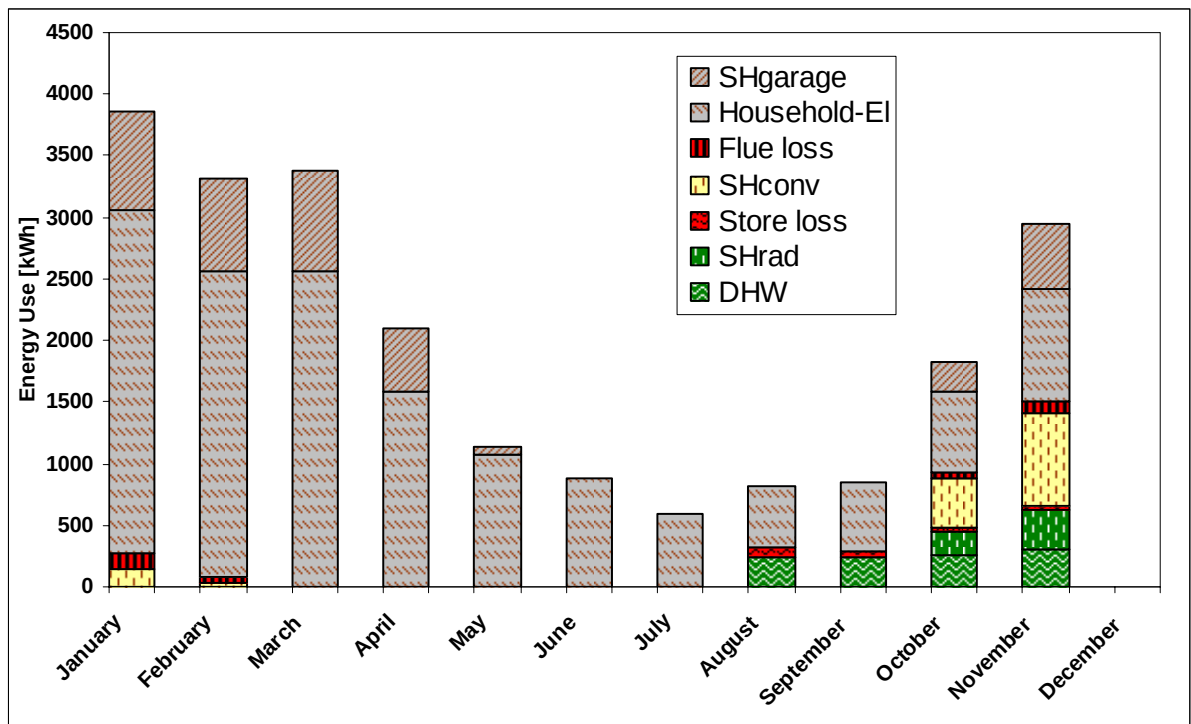


Figure B-6: Monthly energy use during 2006 at the demonstration house. “SH” refers to space heating, “conv” to convective/radiative gains from wood/pellet stove, “rad” to supply to the radiators.

Figure B-6 shows the monthly energy use. The flue gas losses have been estimated based on data from the lab. Pellet supply was measured manually by the owner. The store losses have been calculated based on an energy balance for the store. It is readily apparent that the garage requires a significant amount of heating, with heating occurring even in May. The hot water use has been more or less constant during the monitoring period, averaging 8-10 kWh/day. The store losses decreased significantly after September, showing that the store was at a much lower temperature on average. During August the losses were estimated to be on average 100W, although this figure has a relatively high degree of uncertainty as it is calculated from the differences of much larger energy quantities.

The proportion of heat delivered from the stove to the water is less than half, the rest being supplied directly to the room by convection and radiation. This is much smaller than the nominal proportion for the stove. A closer analysis of the results revealed that the stove was turned on and off more frequently than necessary, resulting in added heat transfer to the room during cool down. At the end of December 2006, this was fixed and the operation was improved significantly.

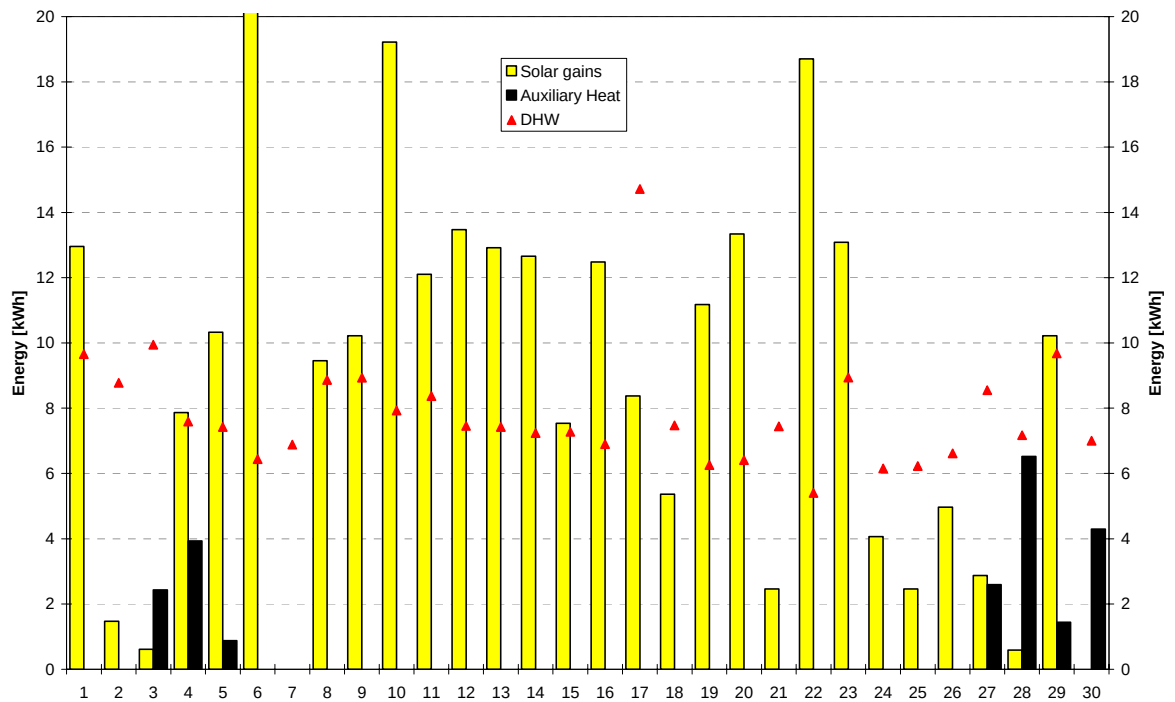


Figure B-7: Daily energy values for September 2006.

Figure B-7 shows the daily energy values for September 2006. The DHW load varied from 5.5 kWh to nearly 15 kWh, but was often around 7 kWh/day. The solar gain was 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 store, which has a volume of only 360 l.

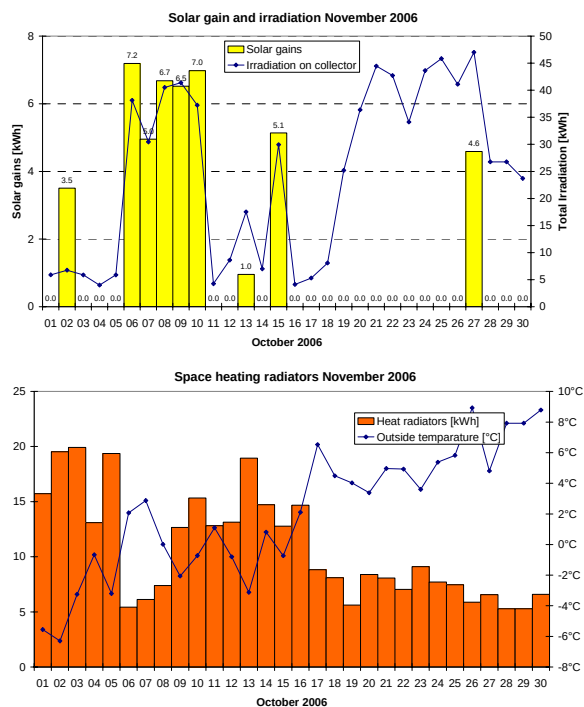


Figure B-8: Daily energy values for November 2006, (left) solar gains and radiation and (right) heat delivered from radiators and ambient temperature.

Figure B-8 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 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 heat delivered from the system comes from the radiators (see Figure B-9), the majority coming directly from the stove. Roughly half of the heat from the stove goes to the water circuit, the rest to the room. This is far less than the nominal 80% that is usual for the stove in the lab under constant conditions. A detailed analysis of the data revealed that the standby store is slightly too small for the current settings of the internal stove and main controllers. By connecting the standby store slightly differently and by moving one sensor, a reduced number of starts/stops could be achieved. This change was made at the end of December 2006 and the detailed results for after the changes could not be shown here. Alternative solutions with improved control algorithms but with the original connection are being considered for the future.

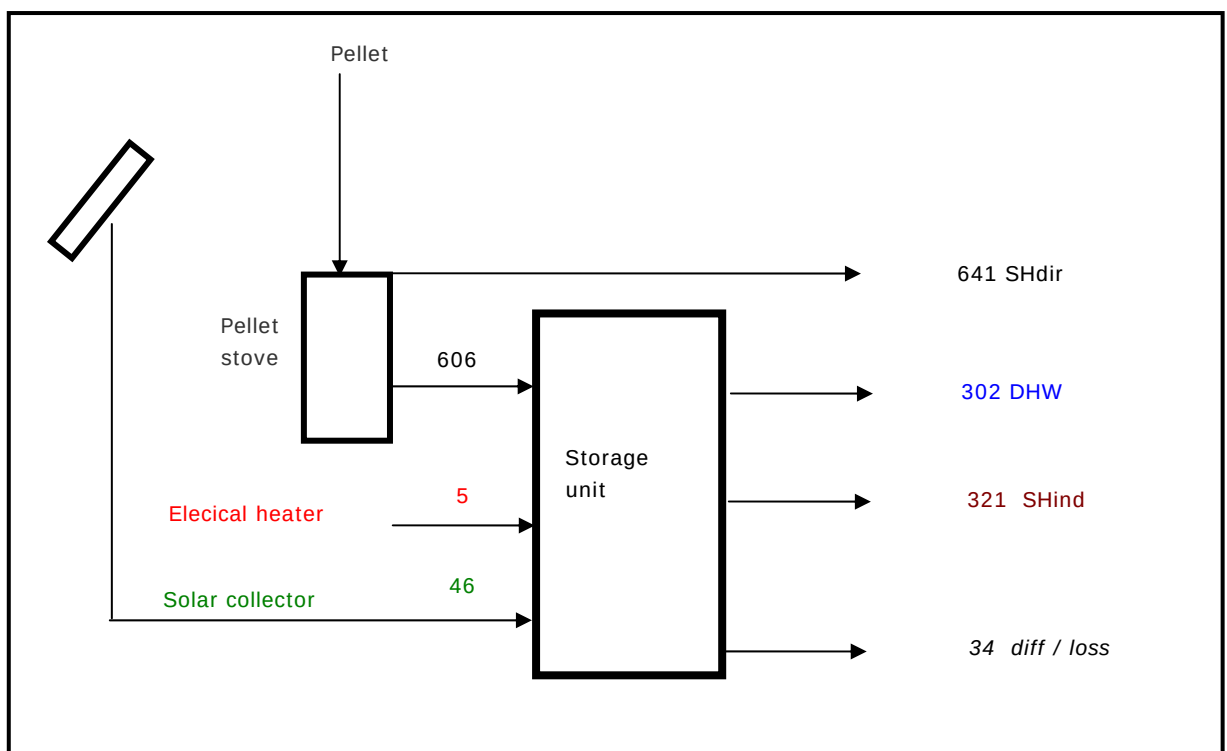


Figure B-9: Monthly energy balance for the system in November 2006.

Dissemination

The following activities have been made to disseminate the results of the REBUS and SCAS projects:

- Participation at the project meeting at DTU, Copenhagen, Denmark, 13-14 November 2006. Chris Bales and Frank Fielder.
- Contributions to the REBUS/SCAS newsletters. Chris Bales, Frank Fiedler.
- Presentation of the project results at the DANVAK meeting, DTU, Copenhagen, Denmark, 14 November 2006. Frank Fiedler.
- Organisation of a seminar on building and system integration of solar thermal energy in Örebro, Sweden on 28th November 2006. 70 participants from industry, consultant companies, architects, local planners, government officials and university research groups. All presentation are

available for download at the REBUS/SCAS website. The seminar was joint arrangement with the EU project NEGST. Chris Bales.

- Presentation of the REBUS system in reports for the EU project NEGST. Chris Bales, Klaus Lorenz. Reports D1.1 and D1.2 on the NEGST website.
- Article on the Danish/Swedish REBUS system to be published in Energimagasinet (Swedish). Chris Bales.

All presentations from the two workshops as well as the newsletters can be found at the REBUS website

Collaboration with Industry

The development work and demonstration were carried out in close collaboration with the Swedish partner Solentek AB and the main Danish partner Metro Therm A/S as well as controller developer Lodam A/S. The second prototype units (technical and solar store) were supplied free of charge by Metro Therm. The collector circuit hydraulic unit was developed and made by Solentek AB, who also supplied the collectors and water jacketed stove to the demonstration system.

Outlook

The demonstration system will be monitored for at least one full year. The monitored data will be analysed in a Masters Thesis project by a student from the European Solar Engineering School (ESES) run by SERC. It will be compared with data from another pellet and solar heating system monitored in 2002/3. Solentek AB and Metro Therm A/S will discuss how to proceed with the development and commercialisation. Relatively little is required in terms of development of the system with the separate pellet stove apart from a further analysis and possible change in control algorithm 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 having some sort of warm storage space.

The REBUS system will be compared to others in the European project NEGST, in terms of monitored results. This will be done in 2007.

Appendix 3: Activities at Univerity of Oslo

Reported by M. Meir and J. Rekstad, University of Oslo

Introduction

The research activity at the University of Oslo (UiO) is strongly linked to various topics related to a solar heating concept with polymeric collectors and a complete reviewed solar heating system design, which was developed by the research group in the 1990's. While the basic solar heating concept is today produced and marketed by the Norwegian company Solarnor AS, the research at UiO focused on further development of the system design, on new applications and modifications suitable for the Nordic market.

The research at UiO was lead by Prof. John Rekstad and Dr. Michaela Meir and carried out together with the Energy group and the Nordic partners. The following sections will give an extended summary of the various research activities and references for further reading.

A 3.1 The Solarnor concept

The present system includes a glazed polymeric collector and a completely reviewed design of a solar heating system, hereafter called "Solarnor-concept". The Solarnor concept is rather un-traditional and designed in the 1990s by starting "from scratch". With the exception of the domestic hot water, the entire hydraulics is non-pressurized (figure 2). The Solarnor system concept is characterized by:

- Low-cost polymeric collectors with moderate efficiency instead of metal-based selective collectors;
- Drain-back technology and avoidance of antifreeze additives;
- Non-pressurized heat buffer store of stainless steel instead of pressurized store; elimination of expansion vessel, simple hydraulic design, lower costs;

The lightweight, modular collector is easy to transport, handle and install. The polymeric collector is available in various dimensions and easy to adjust to given roof-/ facade shapes. The roof-/facade-integrated collector installation (figure 1) replaces conventional materials and contributes to cost savings. Roof-/facade-integrated installations offer more appealing architectural solutions. Several design aspects aim to compensate for the collector's moderate efficiency: The application in solar combisystems or in systems with a large DHW demand and avoiding heat exchangers favour a low system temperature and allow the collectors to operate at a higher efficiency. The system controller regulates all functions: Space heating control, solar heating system control, and energy metering function.



Fig.1 Houses with Solarnor solar heating systems in Oslo (left and middle) and Malmö, Sweden (right). Source: Solarnor (left and right); middle: Ståle Skogstad.

The development of the Solarnor concept was driven by considering the demand side for (solar) heating systems in Central and Northern European climate, which is to provide domestic hot water of temperatures up to approximately 60 °C and to heat buildings to an indoor temperature in the range of 20-25 °C. This is basically a low-temperature heating demand and can be covered by solar collectors of moderate efficiency. The collector area of such systems normally covers a large surface of the building and it is important to consider aesthetics and the architectural integration of the collectors into the roof or facade by substituting conventional building materials. Hence, the collector materials should fulfil the demands of standard building elements. Further the modules should offer flexibility with regard to dimensions, low weight, easy handling and be cost-competitive to conventional energy sources.

A polymeric collector (figure 3) produced by extrusion was considered to meet these requirements better than metal collectors. The development was also strongly influenced by the Norwegian energy market where abundant and low cost hydroelectric power was accessible (approximately 0.06 EURO/kWh until 2002) and approximately 80% of the buildings in Norway were heated by direct electric heating. A considerable increase of the electricity prices the last years (presently 0.10 EURO/kWh) has moved the market toward other energy carriers. One consequence is that water based floor heating has obtained large market shares (approx. 40%) in new residential buildings. Hence, moderate collector- and system costs were playing a major role in the development of the Solarnor collector- and system concept. A major obstacle was that water-based heating systems, which are necessary for solar heating systems, have rarely been installed in new houses since 1960. This has changed around 2000, but still a large amount of buildings is not easily accessible for retrofit with the present concept.

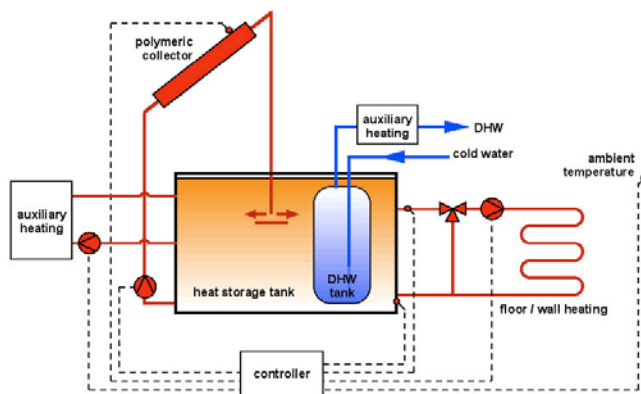


Fig.2 Hydraulic scheme of a solar heating system with drain-back design and polymeric collectors

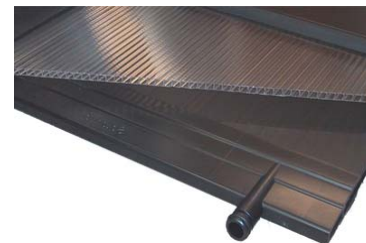


Fig.3 Solarnor collector, detail.

Further reading:

More information on the Solarnor concept, can be found on Solarnor's website (<http://www.solarnor.no>). A comparison of the Solarnor concept to a more conventional solar heating system can be down loaded here:

http://www.swt-technologie.de/NEGST_WP1.E7_norwegian_combi_2006_03_29.pdf

A 3.2 Building integration of solar collectors

Motivation - In the last decade, combined solar systems for domestic hot water preparation (DHW) and space heating (solar combisystems) experienced a considerable market growth in the middle and in northern Europe (Weiß, 2003). Requiring larger collector areas, building-integrated collector installations become a natural choice for solar combisystems.

Traditionally, solar collectors have been mounted on roofs. Due to the low declination of the sun during the heating season from the middle of September to the middle of March, the integration into the façade represents an obvious alternative to roof integration in the Nordic countries. The façade integration opens new opportunities for decision makers, building planners and architects by introducing coloured absorbers. Façade collectors can be seen as multi-functional building modules, providing energy, new possibilities of façade design and surface protection for the building

A 3.1.1 Roof versus facade integration

The project aims to design solar heating systems for Nordic conditions which can cover up to 50 % of the total heat demand in residences. Key factors are among others to improve the thermal insulation of the houses and to increase the collector area. By integrating the solar collectors in the roof or façade, conventional building materials are replaced and the construction material costs can be reduced. The heat demand in Nordic and middle European countries is a low-temperature heat demand with system temperatures in the range of 25-60°C. This application does not require high efficient collectors at high temperatures. Hence a low-cost solar collector made of polymeric materials can meet these requirements. When high solar fractions should be reached, the costs per square meter collector area become a key issue due to the large collector area required.

Solar combisystems, which are designed for solar fractions of 50 % on a yearly basis, will more often reach stagnation conditions during summer time. The risk for stagnations and overheating can be reduced by the integration of the collectors into the façade. This is demonstrated by simulations in the following section. In addition, the reflection of solar radiation due to snow on the ground is another positive aspect against the mismatch between the availability of solar radiation and heating demand.

The simulation program SolDat (Haugen, 2000; Ingebretsen, 1992) was used to generate climate data and study the solar gain of a well-insulated single-family house with a solar combisystem and polymeric collectors.

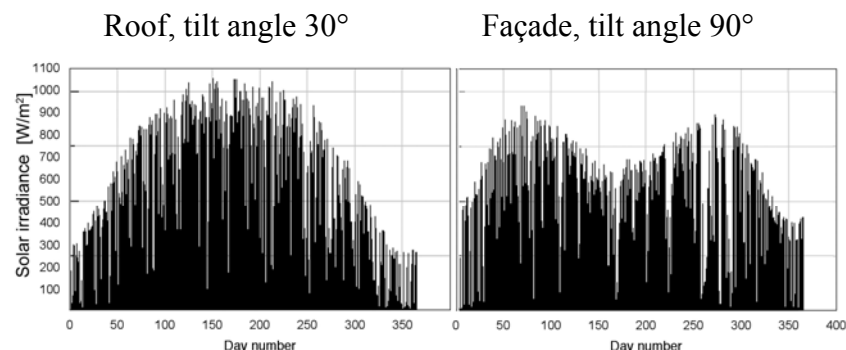


Fig. 4. *Solar irradiance per square meter on a roof with 30° tilt angle and on the façade (90° tilt angle) calculated with the simulation program SolDat for the location Oslo (latitude 59.9°).*

Figure 4 compares the solar irradiance per square meter on the roof (tilt angle 30°) and on the façade (90°) for a house at the location Oslo (latitude 59.9°). The irradiance on the façade collector is better correlated with the space heating demand on an annual basis and will avoid high stagnation temperatures of the collector during summer time. Stagnation occurs when the solar collectors are not cooled by the heat carrier. In the case of the present polymer collector, the heat carrier is then drained to the heat storage and the absorbers are filled with air (drain-back).

If stagnation cannot be avoided, the system design should be so that the collector's stagnation temperatures are not harmful to the material. From the irradiance and the ambient temperature, the stagnation temperatures were calculated for a roof and a façade integrated collector (location Oslo). It is evident that façade collectors are exposed to a much lower thermal stress during stagnation than roof collectors.

Table 1. Stagnation temperatures of the polymer collector for roof and façade integration for Oslo climate calculated with the simulation program SolDat.

Month	Max. ambient temperature [°C]	Collector stagnation temperature [°C]	
		Roof (30°)	Façade (90°)
January	-1	45	65
February	3	75	90
March	7	95	95
April	15	113	103
May	20	120	100
June	28	130	115
July	27	130	105
August	24	125	107
September	20	115	101
October	13	95	102
November	8	65	85
December	4	41	50

Even for Nordic climates as in Oslo, it is possible to reach solar fractions up to 50% for solar combisystems in single-family houses, provided the houses are well-insulated, with low-temperature heating (floor-/wall heating) and have a low annual heat demand in the range of 50 kWh per square meter heated living area.

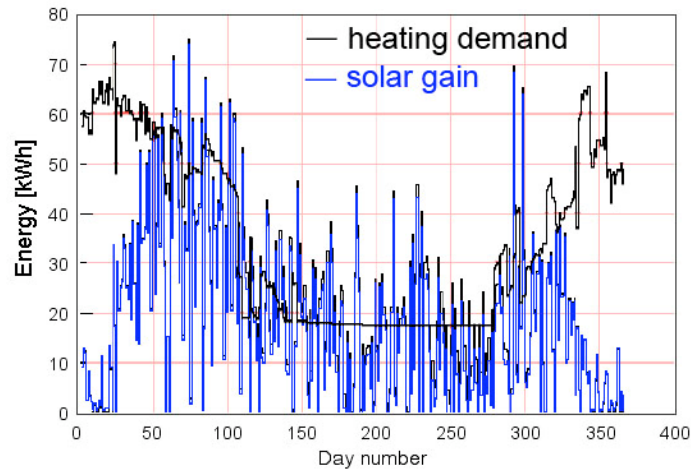


Fig.5. Solar combisystem with façade collectors: Total heating demand and solar gain of a well-insulated single-family house for Oslo climate, calculated with the simulation program SolDat.

Figure 5 shows the total heat demand and the solar gain for a house with an annual space heating demand of 7800 kWh/a and a DHW demand of 5400 kWh/a (includes DHW supply to washing machine and dishwasher). The heat storage volume was 2 m³ and the collectors were polymeric collectors with an area of 40 m², integrated in the south-facing façade. The solar fraction for the system with façade collectors was 59%.

The solar fraction is approximately 12 % higher for façade collectors than for roof collectors, see Table 2. The solar gain per square meter collector area is with 185 kWh/a rather low. However, such systems are feasible with low-cost collectors as the present polymeric collector, which produce energy and substitute standard facade covers.

The calculations give a conservative estimate in favour of façade-integrated collectors. Façade shading during summer time (stagnation) and reflection due to snow during wintertime (performance) have not been considered in the simulations with SolDat.

Table 2. *Comparison of façade- and roof collectors: Heating system data for simulations with SolDat and calculated performance of the solar combisystem with façade- and roof collectors for a well-insulated single-family house.*

Heating system data for simulations	
Heat storage volume	2 m ³
Façade collectors, tilt angle	90°
Collector area	40 m ²
Annual space heating demand	7441 kWh/a
Annual domestic hot water demand	5120 kWh/a

Performance for roof and façade integrated collectors		
	Façade (90°)	Roof (30°)
Solar fraction [%]	59 %	52 %
Solar gain, total[kWh/a]	7434	6537
Solar gain, space heating [kWh/a]	4000	3070
Solar gain, DHW heating [kWh/a]	3435	3466
Solar gain /m ² [kWh/(m ²	185	163

A 3.1.1 Building Physics

The building physical consequences of a "direct integration" of solar collectors in a façade of timber-frame construction for Nordic climate were investigated within the Nordic project REBUS. Wooden houses are very common in the Scandinavian countries. A ventilated cavity behind the cladding of timber-frame walls is usually considered as good practice in order to avoid moisture-induced damage in the construction (Kumar 1998). However, its necessity has also be questioned (Bergmann and Weiß, 2002; Hansen et al., 2002; Tenwolde et al., 1995). By introducing solar thermal collectors as façade integrated modules, the thermal performance and the humidity transport changes. Due to passive solar heating even when the solar system is not operating, the temperature in the wall is higher compared to a wall without collectors and the risk for moisture-induced damages may be reduced. In the present measurements a collector façade with and without ventilated cavity is studied. It should be examined whether a simplified wall construction, in which the façade's insulation simultaneously is the collector insulation and the ventilated cavity is omitted, is feasible from the building physics point of view.

The measurements were carried out in a small test house with a south facing façade of 12.5 m² at the University of Oslo. Fig. shows the horizontal cross section of the test-house's exterior walls. The walls are constructed according to the Norwegian building standard, but have 100 mm mineral wool as insulation, instead of 200 mm as usual by the current building regulations. The modular width of the polymeric collector (Solarnor) matches the width of 60 cm given by the Norwegian building standard. The south-facing façade of the test house had

two fields of integrated collectors with an aperture area of 1.7 m² each. For one field, the collectors with thermal insulation and plywood board replace the exterior cladding, but include the ventilated cavity (Fig. b). The more interesting and more simple way of integration (costs, installation time) is the construction shown in Fig. c, where the ventilated cavity is omitted and the façade's insulation is at the same time the collector's insulation. Here, 12 mm bituminous wood fibreboards (Hunton, 2003) are used as wind barrier, in order to provide mechanical support to the absorber and to withstand the higher temperature of the collector façade.

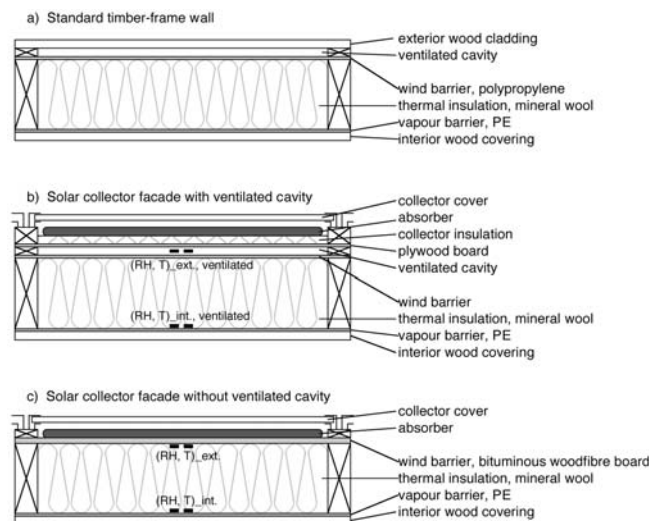


Fig. 6 *Horizontal cross section of the façade walls in the test house: Standard timber-frame wall (a), with integrated solar collectors in a façade with (b) and without (c) ventilated cavity. The position of the sensors measuring the relative humidity (RH) and the temperature (T) is shown.*

Although the dimensions of the present test façade are smaller than required by the Norwegian building regulations, the study gives an indication of the building-physical consequences of an integrated collector façade. During the summer period, the collector and the wall layers underneath are cooled when the solar system is operative. The temperature in the wall layer directly behind the solar collectors was -as expected- higher for the wall without ventilated cavity (Meir et al., 2004).

The relative humidity on surfaces should be below 80% in order to avoid degradation due to fungal attacks (Geving and Thue, 2002). The most important and simple observation from the humidity measurements is that the relative humidity in the wall without ventilated cavity was -except for very few and short peaks- laying considerably below the critical limit of 80% for the monitoring period from June 2003 until May 2004. The measurements during September 2003 and March 2004 are shown in figure 7 and 8. The relative humidity in the wall without ventilated cavity revealed an increase at low level (< 50%) during periods of days with low solar irradiation and high relative air humidity. However, the present construction secures that the relative humidity in the wall reaches the low RH-values with improving weather conditions.

Further reading

The complete study is given in (Meir et al., 2004). For further reading an Austrian study by Bergmann and Weiß (2002) in German language can be recommended. In English language see Chapter 5 in (Weiß, 2003).

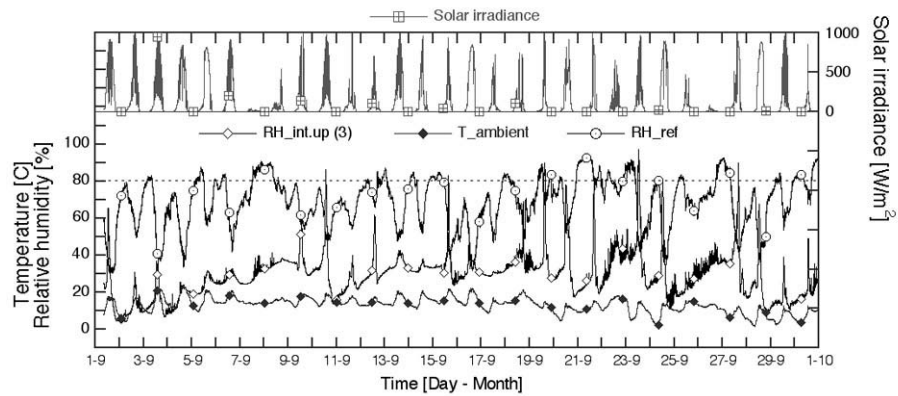


Fig.7 *Relative humidity in a direct-integrated collector facade during September 2003. Shown are the solar irradiance, the ambient temperature, relative humidity of the ambient air (RH_ref) and the relative humidity RH_int.up, measured between thermal insulation and vapour barrier.*

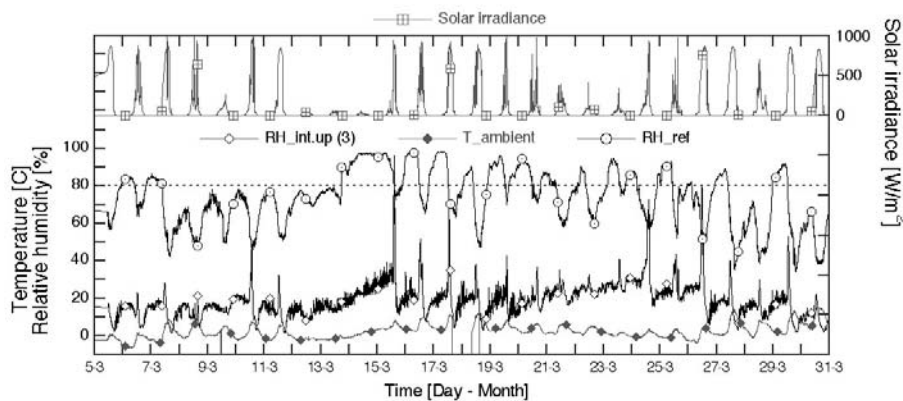


Fig.8 *Relative humidity in a direct-integrated collector facade during March 2004. Shown are the solar irradiance, the ambient temperature, relative humidity of the ambient air (RH_ref) and the relative humidity RH_int.up, measured between thermal insulation and vapour barrier.*

Facade integrated solar collectors: Performance - colours - glazing

The present work studies the façade integration of polymeric collectors for Nordic climate. Different collector covers and different paints on the polymeric absorber were investigated. The collector is part of a drain-back system with water as heat carrier.

Within the EU-project Colourface spectrally selective paints were developed for metal absorbers and demonstrated in pilot projects (Müller et al., 2004). Colours on metal absorbers for installations on flat or inclined roofs in Mediterranean climate were studied with regard to performance and aesthetics (Tripanagnostopoulos, 2000).

This section presents laboratory studies on façade-integrated collectors with black, selective and non-selective, coloured absorbers. The performance was investigated with glass and polycarbonate as collector cover. Consequences for the solar heating system design by introducing façade collectors are discussed.

The absorber - The polymeric material of the present absorbers principally opens the possibility to choose the colour as a property of the bulk material during the

extrusion. This is feasible when a certain production volume for the coloured absorber is given.

In the present studies, the absorbers were coloured by a Thickness Insensitive Spectrally Selective paint (TISS) in the colours green and blue (Köhl, Orel et al., 2003). The TISS paints were demonstrated for conventional metal absorbers within the EU-project Colourface (Müller et al., 2004). The TISS paint coatings are applied on the polymeric absorbers without surface priming. The coatings revealed good adhesion and no visible degradation during the tests.

The absorptance for the unpainted black absorber and for the colours green and blue, were measured with an spectrophotometer model 746 from Optronic Laboratory, USA owned by the Solar Energy Research Centre (SERC) at Höskolan Dalarna in Borlänge, Sweden. The absorptance spectra are shown in Fig. for the wavelength range of 350 nm - 2500 nm. The uncertainty of the absorptance measurements is approximately 1%. The emittance of the TISS paint coatings on metal absorbers was reported by Köhl (2004): $\epsilon_{\text{green}}(373 \text{ K}) = 0.45$ and $\epsilon_{\text{blue}}(373 \text{ K}) = 0.40$.

Table 3. Solar absorptance of the coloured and the black polymeric absorbers.

Colour	Absorptance for $\lambda=350\text{-}2500 \text{ nm}$
Black, non selective	0.94
Green TISS, 9	0.81
Blue TISS, 8	0.82
Green non-selective	0.92
Blue non-selective	0.83

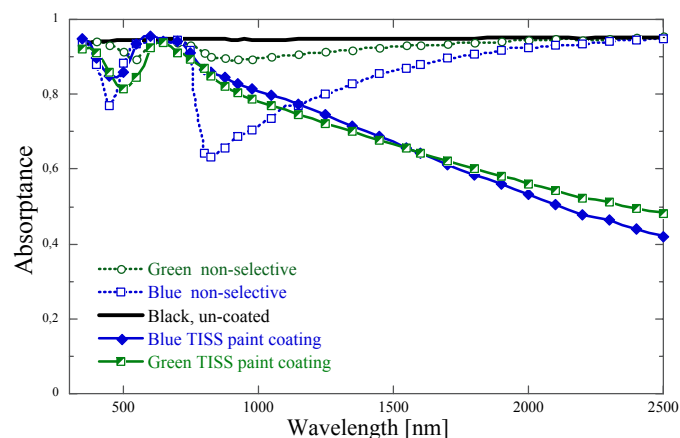


Fig.9. Absorptance of the non-coated black absorber, of the absorber coated with green/ blue TISS paints and with non-selective green/blue paints.

The weighted solar absorptance (Duffie and Beckmann, 1991) of the various colours is listed in Table 1. The table compares the absorptance of TISS paints with commercial, non-selective, alkyd-based paints, which were applied and tested earlier (Meir, 2004; Svåsand, 2003).

Collector cover - The present polymeric collector is commercially available with polycarbonate (PC) twin-wall sheet of 10 mm thickness with rectangular intrinsic structure as collector cover. As glass façades are very common for larger and

commercial buildings, the performance of the collector with black NORYL® absorbers was also investigated with solar glass EUSOL-T/4.0 mm from the company EUSOGLA, Germany. The physical properties of both collector covers are compared in Table 4.

PC twin-wall sheets are available in dimensions, which correspond to the polymeric absorber. Further advantages are the low weight for the transport and the handling during the installation.

Table 4 Physical properties of the collector cover: Polycarbonate (PC) twin-wall sheet of 10 mm thickness and solar glass of 4 mm thickness.

Collector cover	PC twin-wall sheet	Solar glass
Thickness ¹ [mm]	10	4
Transmittance, solar spectrum ¹	0.86	0.91
Weight ¹ [kg/m ²]	1.7	10.0
Refraction index, T=25°C	1.59 ¹	~ 1.50
Thermal expansion [K ⁻¹]	10 ⁻⁵	~ 3 x 10 ⁻⁶
U-value ² [W/(m ² K)]	3.5	~ 6.0

¹ The values refer to the PC twin-wall sheet LEXAN LTC10/2RS from GE Plastics and to solar glass EUSOL-T/4.0 mm from EUSOGLA respectively.

² Refers to the application as window glazing.

The collector-performance measurements were carried out at the Sol-lab, a small test laboratory at the University of Oslo from summer to autumn 2004. Following collectors were tested:

- Black, non-coated NORYL absorber, cover: 10 mm polycarbonate twin-wall sheet
- Black, non-coated NORYL absorber, cover: solar glass EUSOL-T/4.0 mm
- Absorber coated with blue TISS paint, cover: 10 mm polycarbonate twin-wall sheet
- Absorber coated with green TISS paint, cover: 10 mm polycarbonate twin-wall sheet

The different collectors were mounted on the south-facing façade (tilt angle: 90°; azimuth: 18°). The efficiency was determined with the calorimetric method (Svåsand, 2003), collector area: 1.7 m², heat storage volume: 81 litres. The stagnation temperature was determined in separate measurements.

Fig. shows that the façade collector performs somewhat better with the glass cover at small values for $(T_c - T_a)/I$ while the collector with PC cover performs better at large values for $(T_c - T_a)/I$. A solar combisystem with the polymeric absorber is designed so that the typical range of operation for the $(T_c - T_a)/I$ -value is between 0.02 (K m²)/W and 0.06 (K m²)/W. In this range, the efficiency is in the same order for both cover materials. The selection of solar glass or polycarbonate as collector cover will be more dependent on the design of the façade, the aesthetics, material and installation choice and costs.

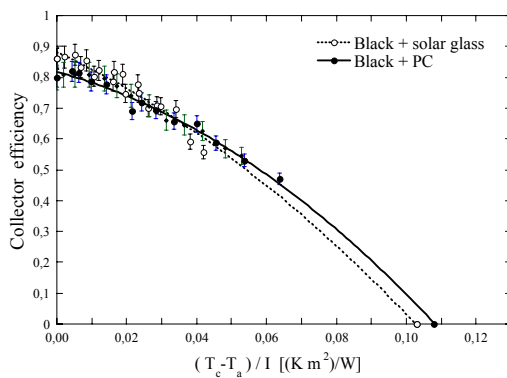


Fig.10. Measured collector efficiencies of the black, non-coated polymeric absorber with two different collector covers: 10 mm polycarbonate twin-wall sheet (PC) and 4 mm solar glass.

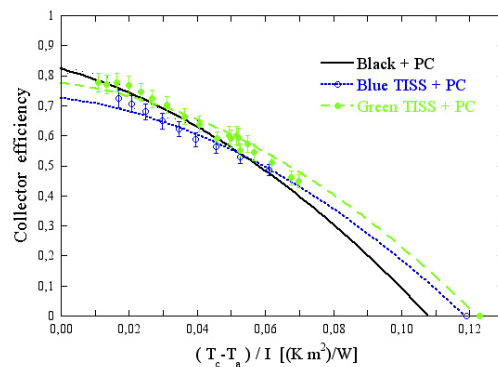


Fig.11. Measured collector efficiencies of polymeric absorbers painted with blue and green TISS paints and with 10 mm polycarbonate twin-wall sheet (PC) as collector cover.

In figure 11 the efficiencies of polymeric collectors (standard PC twin-wall sheet as cover) with non-coated (black) absorbers are compared with absorbers painted with blue and green TISS paints. For small values of $(T_c - T_a)/I$, the efficiency of the collector with black absorbers is larger than for those with TISS paints as expected from the absorptance spectra (figure 9). However, the difference between the efficiency measurements with the blue and green TISS absorber cannot be explained from the absorptance. For the data of "Blue TISS+PC" only one set of measurements was available, while the data of "Green TISS+PC" are from tests of several days.

When it comes to the selection black or coloured absorbers (and which colour) for façade integration, the aspect of aesthetics will be most important. According to studies among architects in Austria, 85% would prefer coloured collectors instead of black and accept the reduction in performance (Bergmann and Weiß, 2002). This study referred to a market dominated by metal absorbers with costly selective coatings relative to the polymeric absorber. The present TISS paint coatings are not a commercial product today. From the point of aesthetics, the TISS paints are estimated to be very competitive and have been demonstrated in other colours than the present green and blue (Müller, -).

Further reading

The complete study is given in (Meir et al., 2005). For further reading, see (Müller et al., 2004) and (Müller et al., -).

A 3.1.3 Study of Systemhus Type-house "Karakter"

During the active period of REBUS the Norwegian type-house company SYSTEMHUS and the REBUS partner Solarnor launched the first Norwegian type-house series¹ with option for solar heating called KARAKTER. The intention has been that the Energy research group at UiO together with Solarnor performs energy monitoring in one of the first installed, solar heated type-house projects. However, delays with the launching of KARAKTER and with arranging

¹ According to a study of the German market offered 24% of the requested building companies of prefabricated houses the installation of solar collectors as an alternative in their advertising (Fiedler, 2003).

the building formalities of the first projects initiated that the project in section A 3.1.4 was selected instead for energy monitoring.

In a collaboration with the REBUS partner at SERC a theoretical study of the type-house KARAKTER was performed in a master project. An introduction of this study and the reference to the complete master thesis is given below.

A large fraction of the private houses in Norway are so-called "type-houses" (typehus). In 2001 were 82% of the new installed houses in Norway type-houses. Type-houses are pre-designed houses for living, mostly of wooden construction. They are standardized and made for mass production with the aim to simplify the building process and reduce costs. In contrast to a pre-fabricated house, the type-house is built step by step on-site. Type-house customers choose from a pre-designed selection of houses with the possibility of certain individual adjustments. The type-house company or a contractor takes over the complete process from the application of the building permission to the house construction including technical and sanitary installations, kitchen, floor and wall covering. New is that the addressed customer is not longer the group of enthusiasts with special interest in renewable energy.

Systemhus, a large Norwegian type-house producer introduces façade collectors for solar thermal heating in the concept of a new designed series of the type-house "Karakter" (Jo Aastorp, Arkitektstudio AS). Herewith, standardized solar thermal heating is offered to a new market and is accessible to customers who might have different motivations to choose the heating source than builders of individual houses. The design of Karakter is functionalistic, adjusted to modern living style and can be modified in order to fit to various grounds. One version of the Karakter type-house is shown in Fig.. The area of the solar collector façade is approximately 20 m², the heat storage 2 m³ with gas as auxiliary heating. The solar fraction is expected to be in the range of 20-30 % dependent on the location. This is due to the relatively small collector area available on the south-facing facade and due to moderate insulation standard in mass-produced housing.

The concept of Karakter has been awarded for the innovative design in 2003 (Boligprodusentenes Nyskappingspris 2003).



Fig.12. *Type-house KARAKTER, example of a standardized single-family house for mass production with façade collectors (left); plan of the 1st floor (middle) and of the 2nd floor (right) (Source: Systemhus).*

Simulation studies were performed in (Gao, 2005) with the computer software IDA (IDA, 2004) and Prebid (Prebid, 2004), see Table 5. The thermal insulation of the building and the dimension of the solar heating system were varied and the energy performance of the building investigated.

The modelling with the program IDA is described in detail and results are presented in Chapter 3 of (Gao, 2005). In Chapter 4, another computer simulation program Prebid is applied for modelling the buildings. For adoption of the Solarnor solar collector, the SolDat simulation program has given valuable results of the façade integrated solar collectors. The results of modelling were used to draw conclusions for design of the heating system and the optimal orientation of the building as well as the placement of the façade integrated solar collectors. It was also shown that the energy saving technologies do not add significantly to initial expense but do lower the long-term costs.

Table 5. *The simulation software IDA and Prebid (IDA, Prebit, 2004)*

IDA	Prebid
IDA Indoor Climate and Energy (ICE) is a program for study of the indoor climate of individual zones within a building and energy consumption for the entire building. IDA is an object-oriented simulation environment designated to handle a wide range of different types of simulation problems. The systems to be simulated are decomposed into subsystems that are modelled using the Neutral Model Format (NMF). These models are then connected together to form a simulation model of the original system. The equation solver can solve most systems of differential-algebraic equations that can be formulated in NMF. Steady state and dynamic problems can be dealt with, as well as discontinuities in the solutions.	Prebid is an interface for creating the building description of TYPE 56 (multi-zone building) version 4.0. Program Prebid is part of the TRNSYS simulation program. The TYPE 56 Multi-zone Building model provides a more efficient way to calculate the interaction between two or more zones by solving the coupled differential equations utilizing matrix inversion techniques. The effects of both short wave and long-wave radiation exchange are accounted for with an area ratios method. The complex description of multi-zone building is simplified with the use of the stand-alone program Building Input Description, and it's associated pre-processor, PREBID (supplied with the TRNSYS program).

A 3.3 Measurements in situ: SCAS demonstration project, Oslo

It was part of the Nordic projects SCAS to demonstrate and put into practice the research activity carried out in collaboration between the research institutes and the industry partners. For the Norwegian market and the Solarnor concept, the multi-family house in Bjørnveien 119 (figure 13), Oslo was chosen as "demonstration project": It included the Solarnor solar heating concept with polymeric collectors, facade integrated collectors, gas as auxiliary heat source and low-temperature floor heating as heat distribution system. Although several projects, which were completed during SCAS, were suitable as demonstration projects, the project at Bjørnveien has due to its vicinity to the University of Oslo and Solarnor an excellent location and has already been used for numerous excursions with industry, business contacts, researchers and students.



Fig.13 *SCAS demonstration project: The multi-family apartment block at Bjørnveien 119 in Oslo has also been selected as a good example of facade integrated solar collector within the EU project NEGST, "Next generation of solar thermal systems"; source: NEGST coloured brochure.*

In August 2006, the data monitoring equipment has been installed at the solar heating system in a multi-family house in Bjørnveien 119, Oslo. The construction of the building was finished in the end of 2005, when the new owners moved in. The solar heating system was delivered by Solarnor and partners. The aim for this demonstration project is to monitor the energy consumption and the gain of the solar heating system. The measurements will continue until end of 2007. Additionally the "demonstration" consists also in excursions to the site, for teaching, read-out and presentation of the solar heating system.

Background information: The apartment block was finished end of 2005. The high-standard apartments have a living area of 131-161 m². The solar heating system includes a collector façade of 97 m² on two part of the building complex on the southwest-facing façade (figure 14) and contributes to domestic hot water preparation and floor heating. The collector facade consists of polymeric solar collectors (Solarnor AS) as a part of a drain-back system. The buffer storage with 8 m³ is the heating central for the eight apartments.

As illustrated in the hydraulic scheme, the heat store is divided in two section: The "floor storage" is connected to the floor heating systems in the eight apartments. The Solar store is coupled to the two collector circuits and includes four immersed, pressurized 200 l stores for preheating of domestic hot water. The auxiliary heating source is propane gas. The solar heating system is dimensioned for a solar fraction of approximately 20 %.



Fig.14 *Schematic drawing of the multi-apartment complex at Bjørnveien 119 in Oslo (top) and solar collector system with piping and heat store in the technical room (bottom); Source: DDB arkitekter, Oslo, Backe Gruppen AS.*

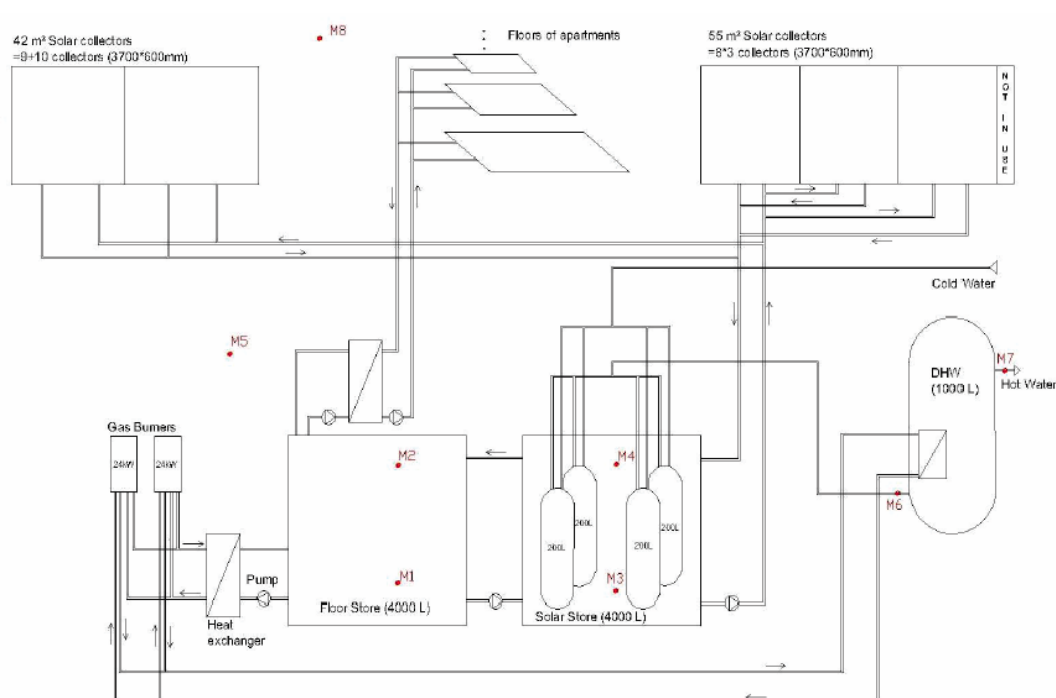


Fig.15 *Hydraulic drawing of the solar heating system at Bjørnveien 119 in Oslo; source: (Pain and Lelandais, 2006).*

Data acquisition - The data acquisition of the heating system in Bjørnveien 199, Oslo is carried out with a datalogger ALMEMO® 2890-9 from Alborn [www.ahlborn.com]. The ALMEMO® 2890-9 data logger, see Fig., has nine electrically isolated measuring inputs. The data logger function is carried out by a real time clock and a 512kB EEPROM memory for approximately 100000 measured values. The user can easily complete or modify the programming via keyboard or via interface. The data logger memory can be read out either in total or selectively in parts and can be saved as a file. The file is exported to analysing software. One photovoltaic pyranometer and nine temperature sensors were installed outdoor and in the technical room of Bjørnveien 119, see figure 16.



- M0: SolData photovoltaic pyranometer
- M1: thermocouple at the bottom of the floor store
- M2: thermocouple at the top of the floor store
- M3: thermocouple at the bottom of the solar store
- M4: thermocouple at the top of the solar store
- M5: thermocouple indoors the room
- M6: thermocouple outlet of the DHW store
- M7: thermocouple inlet of the DHW store
- M8: thermocouple outdoors of the house

Fig.16 Datalogger ALMEMO® 2890-9 from Alborn with temperature sensors and photovoltaic pyranometer. The temperature sensors M0-M8 are installed in the system. Source: (Pain and Lelandais, 2006).

Calorimetric method - The analysis of the measured data is carried out with the calorimetric method (Meir et al., 2002). Although rarely applied, the calorimetric method reveals certain advantages in analysing the solar system performance from in situ measurements. The monitoring parameters of the system are limited to the heat store temperature, the ambient temperature and the global irradiance. Uncertainties related to the mass flow monitoring are thus eliminated. As the extraction of the data is basically related to the heat store, the method is independent on the (solar) system size. Figure 15 shows the placement of the sensors at the solar heating system in Bjørnveien 119. For the calorimetric method the store is the main subject of investigation. It is the central where any changes in temperature are related to the supplied and tapped energy of all essential components in the heating system including the heat losses, e.g. illustrated in the measurements from August 10-17, 2006 at Bjørnveien.

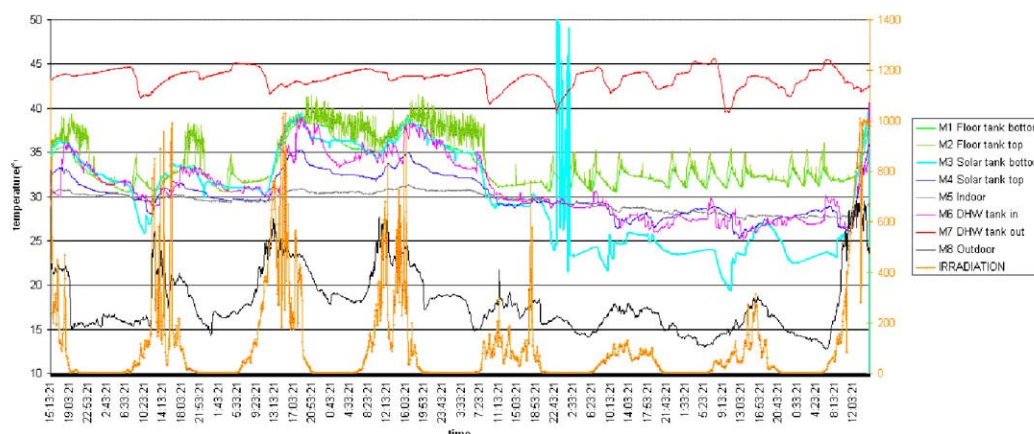


Fig.17 *Measurements of the solar heating system's performance at Bjørnveien 119. Shown are the raw data of the temperatures in the solar-, floor- and domestic hot water stores, the indoor and outdoor temperatures and the solar irradiance for August 10-17, 2006.*

With sufficient statistics, time and seasonal dependant loads can be separated and correlated to the external parameters (in particular ambient temperature and solar radiation). Hence, these correlations can be utilised in the analysis of the periods with simultaneous supply and load. Correspondingly, typical load patterns for the DHW consumption can be found independently and used in the analysis. The duration of the measurements should be long enough in order to secure sufficient statistics for extracting reliable correlations and load patterns.

Although hard work was done with regard to the analysis, it is too early to present data for the first 4 months of monitoring due to who has be described in the last paragraph.

The intention is to present a report of the first measuring period during spring 2007. The measurements for one complete year will be published in the end of 2007 in a master thesis at the Department of Physics, University of Oslo by master student Frode Meek.

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Appendix 4: Activities at RTU

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Introduction

In this appendix is described the specific work developed by RTU in the framework of the project. However the Ph.D. report describing all project research activities and results will be defended in January 2008.

1. Demonstration house

In parallel with the development of the solar laboratory and research activities, an important activities and priority for RTU in the framework of the REBUS project and SCAS project was the development of a demonstration project.

During May and June 2005 five potential houses for the demonstration project have been visited. In middle of June the owner of one of these houses agreed on the terms for the implement the demo project. The house was located in Gauja (see photo below), approximately 30km from Riga, in a region not covered by natural gas. The house had a heated area of 210m² and was recently built (figure 1).

Unfortunately, at the moment of signing a memorandum of understanding in the beginning of July the owner changed idea.



Figure 1. The first potential house for the REBUS demonstration project

During July and August 2005 other houses were investigated in the surroundings of Riga. Discussion with approximately 80 house owners of single-family houses and disseminated information via different channels were carried out.

In the end of Augusts one house owner shown very high interest and his willingness to implement the project – the house is rather big, with 326m² but only 200 m² are heated and it is located in Riga in the residential district of Zemgales Priekspilseta.

Then only drawback is that the owner wants to keep natural gas as auxiliary heat source and therefore this demonstration project will not use the pellet version of the prototype.

To be able to compare the natural gas consumption and energy flows of the house with the old existing heating system and the new solar combisystem, a monitoring systems was installed in year 2006. The solar combisystem will be installed in August 2007.

1.1 Description of the demonstration house

The demonstration house is located in Riga in the residential district of Zemgales Priekspilseta ($56^{\circ}55'18,19''$ N, $24^{\circ}03'55,63''$ E – see figure 2) at the elevation of 11m from the sea level.



Figure 2. Location of the demonstration project in Riga

The house is shown in figure 3, it has 4 floors:

1. Basement including sauna, big bathroom, and the technical rooms
2. First floor including kitchen, living room and dining room and small bathroom
3. Second floor with bedrooms and a bathroom.
4. Attic, which is not heated and only used as storage



Figure 3. View on the demonstration house from the southeast

In the house is currently leaving a family composed by 5 persons, all adults.

The house has been renovated during autumn 2005. The works consisted on improving the building envelop with insulation and changing the old windows. As well as the space heating and domestic hot water systems have been renovated.

The space heating system mainly consists of modern radiators with thermostat valves.

The bathroom at the first floor is equipped with electrical floor heating.

In the sketches in figure 4, 5 and 6 are shown the layout of the three main floors.

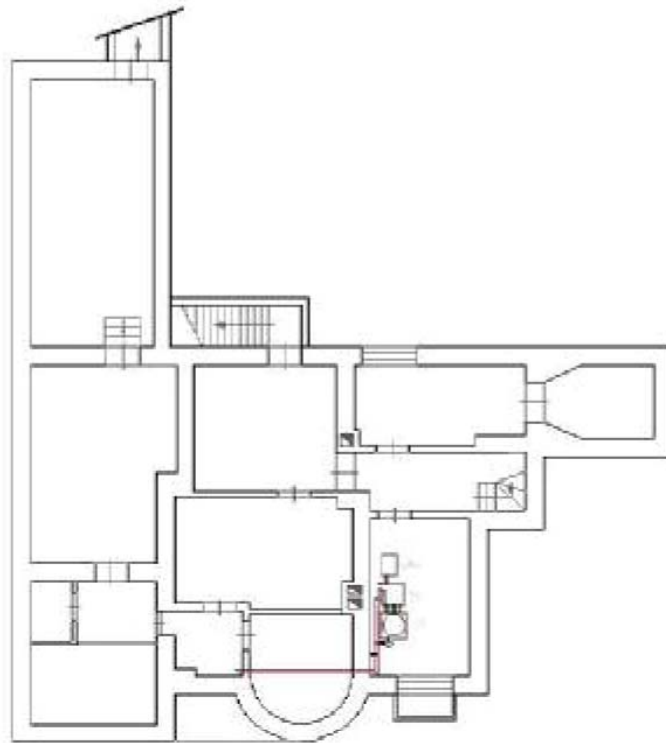


Figure 4. Basement of the demonstration house

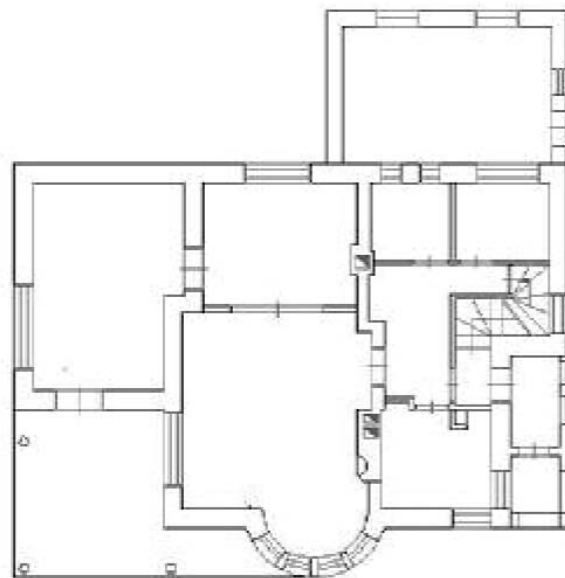


Figure 5. First floor of the demonstration house

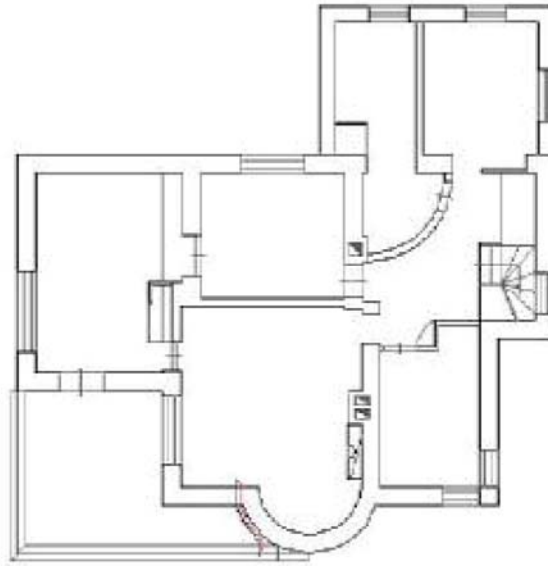


Figure 6. Second floor of the demonstration house

1.2 The old natural gas heating system

A standard non-condensing natural gas boiler powers the existing heating system. In the system is integrated a buffer tank to reduce the number of start up stop phases of the boiler. In summary:

- Natural Gas Boiler: Junkers EUROLINE ZW 23-1 AE, Nominal Power: 23 kW; Construction year: 2001
- Buffer tank volume: 320 liter
- Number of pumps: 2
 - The main pump is integrated in the gas boiler
 - Domestic hot water circulation pump.
- As alternative energy source is still installed in parallel with the natural gas boiler the old wood log boiler, which was used before year 2001. Since the installation of the natural gas boiler this alternative has not been used.

In the house in total 14 radiators are installed, all of them are equipped with a thermostat valve with an integrated room temperature sensor.

The bathroom at the first floor has an additional electrical floor heating – programmed to switch on in the morning to increase comfort only.

1.3 Project for the installation of new solar combisystem

Given that the house owner, when he agreed on the project, he was uncertain on the best solution for the installation of the solar collectors and additionally the house was under reconstruction, 3 alternatives for the installation of the solar system were prepared. Alternative 3 was selected. In the following paragraphs is given a summary of the proposed alternatives.

1.3.1 Alternative 1 – non integrated collectors on the roof

In this alternative it is planned to install the solar collectors on the roof of the building.

As starting point, an approximate area of 10m^2 flat plate collector has been considered.

Collector on the roof could be installed with a tilt between 40° and 55° degrees, south to southeast oriented.

Aesthetically the installation could negatively impact the beauty of the building. In figure 7 is given a graphical interpretation with a photomontage.



Figure 7. Photomontage illustrating the installation of solar collectors on the roof.

Technically this type of solution needs to be further investigated in particular in relation to the structure and framework of the roof, which is rather complex.

1.3.2 Alternative 2 – wall integrated collectors

In this alternative it is planned to integrate the solar collectors in the wall façade facing south.

As well as in this case as starting point has been calculated that an approximate area of 10m^2 flat plate collector has been considered.

The installation of collector on the wall is therefore with 90° tilt angle. The azimuth of the best façade (shown in figure 8) is approximately 20° east of south.

Under the energetic point of view, solar panel vertically installed at northern latitudes have lower efficiency during summer period, but perform better during middle seasons and winter compared to traditional tilted installations.

Aesthetically the installation could positively impact the building, in particular if the collector will be integrated with the new external insulation, which will be installed. In figure 8 is given a graphical interpretation with a photomontage.



Figure 8. Photomontage illustrating wall integrated solar collectors. It is likely that the area on the right hand side of the building is enough large to supply the desired load.

Technically this type of solution is very simple, in particular for the hydraulic connections to the technical unit.

1.3.3 Alternative 3 – balcony fence integrated collector

In this alternative it is planned to integrate the solar collectors as fence of the balcony, which is facing south.

As well as in this case as starting point has been calculated assumed the installation of approximately 10m^2 of flat plate collectors.

The installation of collector as balcony fence can be realized with a tilt between 80° and 90° degrees.

Aesthetically the installation could positively impact the building and provide an attractive solution to the large balcony of the building. In figure 9 is given a graphical interpretation with a photomontage.



Figure 9. Photomontage illustrating balcony fence integrated solar collectors.

Technically this type of solution is very simple, in particular for the installation of the collectors. For the hydraulic connection there is need to bring the supply and return pipes from the collector to the technical unit. In this case there is need to purchase appositely designed collectors.

1.3.4 Selected alternative

The house owner selected alternative 3, which then was further developed. In figure 10, 11 and 12 is given an overview of the project design.



Figure 10. Front view – after installation (collector tilt 80° , length $\approx 6.5\text{m}$ and height $\approx 1.16\text{m}$)



Figure 11. Lateral view – after installation (collector tilt 80° , length $\approx 2.5\text{m}$, height $\approx 1.16\text{m}$)



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Figure 12. Extract of the design concept of the demonstration house

1.3.5 Selected solar accumulation tank

Metro Therm A/S produces the solar tank, which will be used in the demonstration project, with the following characteristics:

- Nominal volume: 360 liter
- Dimensions of cabinet: 595 x 600 x 1820 mm
- Insulation: Polyurethane (PUR) foam and vacuum panel
- PUR-foam, heat conductivity: 0.024 W/mK
- Vacuum panel, heat conductivity: 0.005 W/mK

In figure 13 below are shown two tanks delivered by Metro Therm A/S at the solar laboratory of RTU – Institute of Energy Systems and Environment..



Figure 13. Metro Therm A/S solar tanks. Left, solar tank with volume of 360 l and vacuum insulation. Right solar tank with volume of 300 l and foam insulation.

These tanks, both installed within the 60x60 cabinet, look similar, however one of the tank has a volume of 360 liters and it is insulated using vacuum panel (the use of this panels allowed the tank to still fit in the 60x60 cabinet) and the other is the standard Metro Therm AS tank of 300 liters with foam insulation.

Currently the two tanks are tested and compared in the solar laboratory of RTU.

1.3.6 Selected solar collector

For the implementation of the project have been selected collectors produced in Austria by AEK Doma Solartechnik GmbH.

The general main data about the installation are:

- Geographic position of the house: 56°55'18,19" N, 24°03'55,63" E
- Tilt angle of the balcony fence: 80°
- Azimuth of the Balcony front view: 20° east of south
- Azimuth of the Balcony lateral view: 110° east of south
- Collector: AEK Doma

Technical data of one collector according to the AEK Doma data sheet are:

- Total length: 3.9m
- Total width: 2m
- Net weight: 249 kg
- Gross area: 7.833 m²
- Net area: 7.10 m²
- Absorber area: 6.611 m²
- Liquid content: 2.9 l
- Proofed pressure: 10 bar
- Max. operating pressure: 10 bar
- Stagnation temperature: 144.5 °C
- Start efficiency: 0.74
- First loss coefficient c1: 4.62 W/m²K
- Second loss coefficient c2: 0.0100 W/m²K²
- Incident angle modifier: k1= 0.94 at 50° and k2=0.94 at 50°
- Heat capacity: 47 kJ/K

The connection of the collector to the technical unit is planned with a loop having the following main characteristics:

- Length forward pipe: 14.5 m
- Length return pipe: 22 m
- Inner diameter: 19 mm
- Outer diameter: 22 mm
- Insulation thickness: 14.0 mm
- Heat conductivity: 0.035 W/mK
- Liquid content: 0.28 l/m

1.4 Monitoring system installed in the demonstration house

The existing system is under monitoring. In particular the monitoring systems is aimed to monitor natural gas consumption, natural gas boiler efficiency, space heating consumption, domestic hot water consumption, indoors temperatures and weather data at the site.

Table 1 gives the list of sensors installed and description of their location, both for monitoring the existing system and for monitoring the new solar combisystem. The location of the sensor is shown in figure 14.

Table 1: list of required heat meters and sensors for system monitoring

Type	Auxiliary boiler input	Auxiliary boiler output	DHW	Space heating	Solar collector loop	Indoor temperatures	Weather data
Sensor Number	1	1'	2	3	4	5	6
Existing system	Yes – connection of the gas meter to data logger	Yes – magnetic heat meter to data logger	Yes – flow meter and two T type thermocouple	No – it will be calculated	N/A	Thermocouple type J	Yes – outdoor meteorological station
Solar combisystem	Yes – connection of the gas meter to data logger	Yes – magnetic heat meter to data logger	Yes – flow meter and two T type thermocouple	Yes – magnetic heat meter to data logger	Yes – magnetic heat meter to data logger	Thermocouple type J	Yes – outdoor meteorological station

For the indoor measurement the following data loggers are used:

- Campbell CR10X
- TESTO 735

For monitoring of weather data is used a NOMAD portable weather station with SENSUS data logger.

From January 2007 as well as electricity consumption will be monitored.



Figure 15. The 25kW wood pellet boiler with the pellet store mounted on the side of the boiler

At the beginning of the project it was discussed and agreed that the existing boiler produced by Grandeg did not have a sufficient degree of automation for to be successfully integrated in the prototypes under development. In particular they were missing automatic function for switch on and power modulation possibilities. Moreover the size of the boiler was considered too big for potentially to be integrated in a 60x60 cabinet.

Hence, it was agreed about the possibility to work out and develop a new product. The activities, to be completed in two stages, were planned as follows:

1. Short-term – to start developing a more advance version of the existing 15kW boiler – adding automatic on-off function, electrical switch on system and power modulating function. This activity mainly concentrated on the development of the algorithm and on some minor changes on the boiler structure.
2. Long term objective – to develop a more compact unit, which could be integrated in the 60x60 cabinet of the project prototypes developed in DTU and SERC.

In the charts proposed in figure 16, 17, 18 and 19 are shown and summarized the results from one of the first tests implemented at SIA Grandeg workshop on the first new 15kW developed boiler prototype.

This test was aimed to assess emission level and efficiency of the new prototype and to test the automatic switch on function.

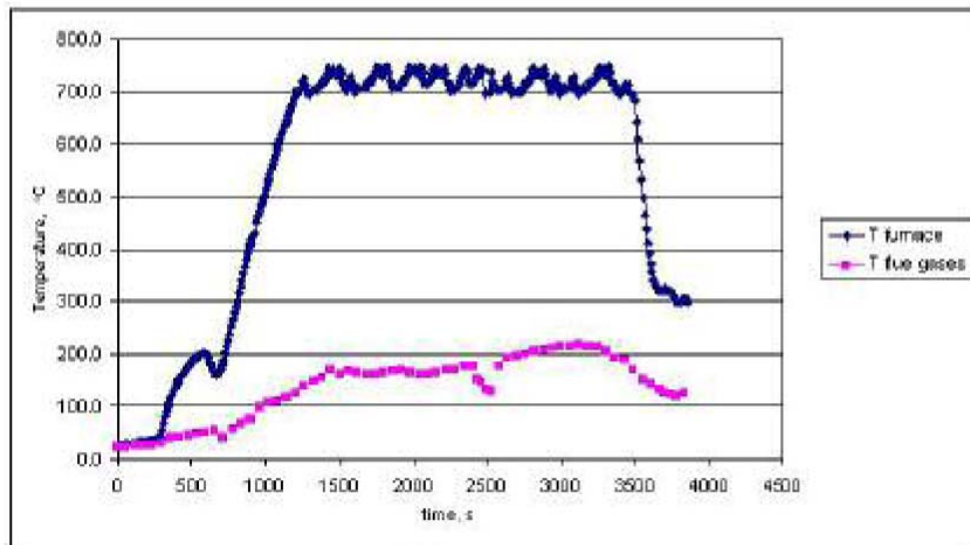


Figure 16. Temperature levels in the furnace and flue gas during a start up – regime – off test. Temperature measured with thermocouples Type J

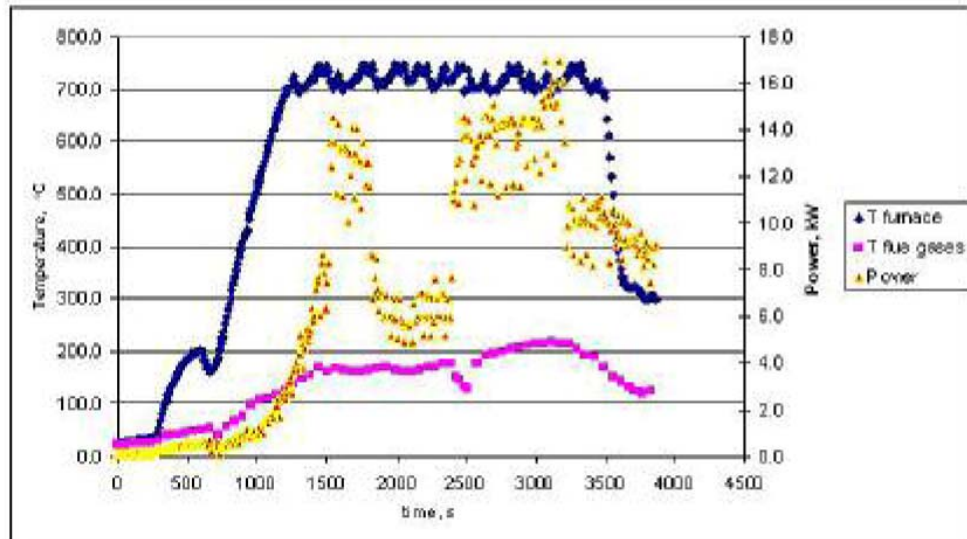


Figure 17. Temperature levels in the furnace and flue gas during a start up – regime – off test and power output. Temperature measured with thermocouples Type J, flow rate measured with ultrasonic flow meter – Panametric.

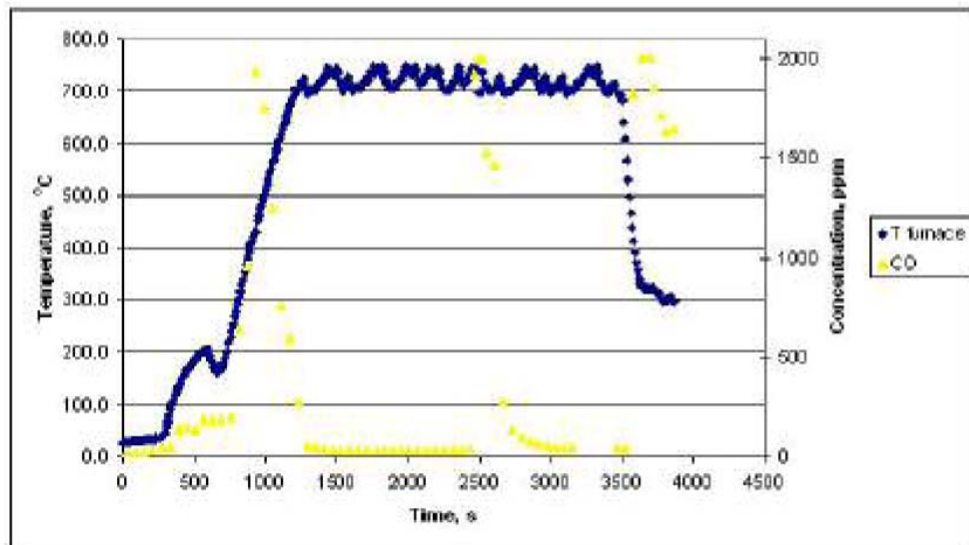


Figure 18. Temperature in the furnace compared with CO emission, measured with TESTO gas analyzer

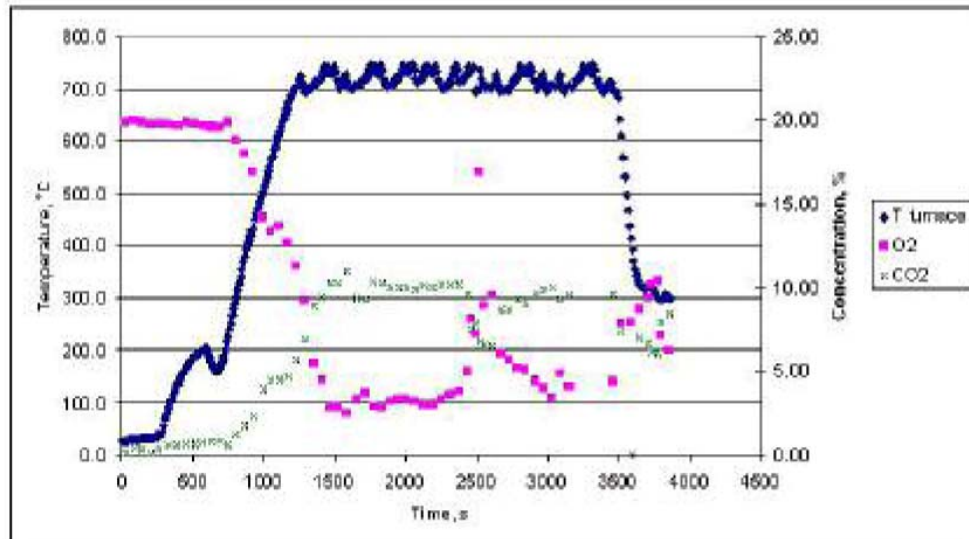


Figure 19. Temperature in the furnace compared with O₂ and CO₂ emissions measured with TESTO gas analyzer

Currently the work is on going on the calibration and tuning of the boiler sensors and improvements of the control algorithm.

The new boiler will be commercialized by October and November 2007. The works on the development of the compact version of pellet boiler will start in summer 2007.

3. Article - EA Enerģētika un Automatizācija

The article titled: *Vai Latvijā pietiek ar Saules siltumu ēku siltumapgādes sistēmai* (Is there enough solar energy in Latvia to supply heat energy to building?) was published on the specialized magazine: *EA Enerģētika un Automatizācija* number 10 of December / January 2006 / 2007.

The cover of the magazine is shown in figure 20.



Figure 20. Cover page of EA Enerģētika un Automatizācija.

In figure 21 is given the scanned view of the published article.



Figure 21: Scanned view of the article

4. Solar Seminar – 27th October 2007

The preparation stage started two months before the event, in the end of August 2006.

The first activity concerned the preparation of the program for the solar seminar. It was decided to include theoretical aspects of solar energy and related environmental issues, to inform the participants on the existing status on solar combisystems technologies and their economical aspects. In the agenda were as well as included example from Latvia and information about the REBUS project and the SCAS project.

The following lecturers were contacted and agreed to held their presentation in the seminar:

- Dagnija Blumberga Riga technical University
- Ivars Veidenbergs, Riga technical University
- Dzintars Jaunzems SIA Venteko
- Andris Lubins, SIA Grandeg
- Maritins Gedrovis, Riga Technical University and Lavijas Gaze
- Agris Kamenders, SIA Ekodoma

The agenda of the seminar was developed as follows:

10:00	Welcome Dagnija Blumberga, Director of the Institute of Energy Systems and Environment, RTU
10:10	Solar combisystems in Latvia – research activities NER – REBUS and Nordisk Innovation Center - SCAS Dagnija Blumberga, Director of the Institute of Energy Systems and Environment, Riga Technical University
10:30	Solar heating possibilities in Latvia Ivars Veidenbergs, Riga Technical University
11:00	Development of solar combisystems – Latvian perspective Dzintars Jaunzems SIA Venteko
11:30	<i>Coffee break</i>
12:00	Use of pellet boilers – possibility with solar combisystem Andris Lubins, SIA Grandeg
12:30	Use of natural gas – possibilities with solar combisystem Maritins Gedrovis, Riga Technical University and Lavijas Gaze
13:00	Passive houses in Latvia Agris Kamenders, SIA Ekodoma
14:00	<i>Solar energy use in Latvia discussion</i>

During the preparation stage approximately 50 potential participants were contacted and informed about the seminar. As a result we received 19 applications for participation to the seminar, which are shown in table 2.

Table 2. Participants to the solar seminar

Nr.	Name	Surname	Company
1	Auseklis	Logins	Vidzemes Siltumnieks
2	Viktors	Petrovskis	Dagdas pilsētas dome
3	Gvido	Stucka	Gulbenes pilsētas dome
4	Jevģenijs	Sobko	Valsts vides dienesta Madonas reģionālā vides pārvalde
5	Gundars	Ozoliņš	A/S "LAFIPA"
6	Romāns	Šehlovs	SIA "Salaspils siltums"
7	Inta	Hahele	Valsts vides dienesta Liepīgas reģionālā vides pārvalde
8	Guntis	Melecis	A/S "Simone"
9	Antra	Zadināne	A/S "Rīgas piena kombināts"
10	Andris	Ancītis	SIA "Papīrfabrika "LĪGATNE""
11	Imants	Saulriets	SIA "Saulkalne S"
12	Edgars	Didrihsons	SIA Vanteko
12	Pāvels	Kotāns	Birzgales pagasta padome
13	Uldis	Lazdiņš	SIA "Jelgavas nekustamā īpašuma pārvalde"
14	Juris	Vidžis	SIA "Jelgavas nekustamā īpašuma pārvalde"
17	Jānis	Rancāns	SIA LEC
15	Harijs	Lediņš	SIA "Sabiedrība Mārupe"
18	Pauls	Krievins	SIA Ekodoma
19	Leonis	Driķis	SIA Sinhro

During of the seminar there were good discussions between the different participants about the possibility to use solar energy and solar combisystems in Latvia.

In figure 22 are given two photos taken during the seminar



1. presentation of I. Veidenbergs about Solar heating possibilities in Latvia



2. Presentation of Dzintars Jaunzems about Development of solar combisystems

Figure 22. Picture taken during the seminar

In figure 23 is provided the of list participants with signatures.

Nr.	Vārds	Uzvārds	Uzņēmums	
1	Auseklis	Logins	Rūjienas pilsētas domes SIA "Rūjienas siltums"	
2	Viktors	Petrovskis	Dagdas pilsētas dome	
3	Gvido	Stucka	Gulbenes pilsētas dome	
4	Jevgeņijs	Sobko	Valsts vides dienesta Madonas reģionālā vides pārvalde	
5	Gundars	Ōzoliņš	A/S "LARIPA"	
6	Romāns	Šehovs	SIA "Salspils siltums"	
7	Inta	Hahele	Valsts vides dienesta Lielīgas reģionālā vides pārvalde	
8	Guntis	Melecis	A/S "Simons"	
9	Antra	Zadināne	A/S "Rīgas piena kombināts"	
10	Andris	Ancītis	SIA "Papīrfabrika "LĪGATNE""	
11	Imants	Saulietis	SIA "Saulkalne S"	
12	Edgars	Didrihsons	SIA "Venteko"	
13	Pāvels	Kotāns	Birzgaļes pagasta padome	
14	Uldis	Lazdiņš	SIA "Jelgavas nekustamā īpašuma pārvalde"	
15	Juris	Vidzis	SIA "Jelgavas nekustamā īpašuma pārvalde"	
16	Jānis	Rancāns	LEC	
17	Haris	Lediņš	SIA "Sabiedrība Mērupe"	
18	Pauls	Krieviņš	SIA "Ekodoma"	
19	Leons	Driķis	SIA "Sinhro"	

Figure 23. Signed list of participants



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