ENERGY SAVINGS FOR SOLAR HEATING SYSTEMS IN ONE FAMILY HOUSES

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1. Introduction

A high number of investigations on the thermal performance of solar heating systems, both under laboratory conditions and in practice, have been carried out. In spite of this, relatively few investigations have focused on energy savings of solar heating systems. This is remarkable, since most solar heating systems are installed with the aim to save energy. The main reason for the few investigations is that it is impossible directly to measure and very difficult to document the energy savings of solar heating systems in practice.

In order to determine the energy savings for solar heating systems, seven energy quantities/efficiencies must be considered.

Before/without installation of the solar heating system:

- Utilization of energy for the energy system
- Electricity consumption for the energy system

After/with installation of the solar heating system:

- Net utilized solar energy of the solar heating system
- Saved energy by turning off the auxiliary energy supply system during the summer
- Utilization of energy for the auxiliary energy supply system
- Electricity consumption for the auxiliary energy supply system
- Electricity consumption for the solar heating system

Further, to make the determination of energy savings of solar heating systems even more difficult, the above mentioned energy quantities and efficiencies are influenced by the heat demand of the house, the hot water consumption and the heat loss of a possible circulation pipe. These quantities will vary from year to year due to weather variations and variations of user habits. Possible changes of the hydraulics of the energy system and domestic hot water system caused by installation of the solar heating system might also influence the heat demand, hot water consumption and heat loss of a possible circulation pipe.

Finally, it must be mentioned, that solar heating systems today are often based on prefabricated energy units including a natural gas boiler and a heat storage. In this way, an improved utilization of the natural gas can be achieved compared to an energy system without solar heating system or compared to an energy system with a separate natural gas boiler and a separate solar heating system.

Furbo et al. (2007), Furbo and Thür (2008) and Furbo et al. (2009) investigated in great detail a new 6.75 m² solar combi system in a one family house based on such a new developed unit. Before installation of the solar heating system, the house was heated by a non condensing natural gas boiler. All the 7 above mentioned energy quantities and efficiencies were measured for a number of years, both before and after installation of the solar heating system. The investigations showed that the yearly energy savings for the solar heating system varied from year to year between 650 kWh per m² solar collector and 730 kWh per m² solar collector. The yearly heat productions of the solar collectors were about 53% of the yearly energy savings.

Larsson (2000) carried out a survey on energy savings of a number of solar heating systems based on questionnaires filled in by house owners on their energy consumption before and after installation of solar heating systems. Solar heating systems with collector areas between 4 m² and 25 m² were included in the investigations. The average collector area of the investigated systems was 11 m². The reported yearly energy

savings varied from 0 kWh per m² solar collector to 2750 kWh per m² solar collector, and typical energy savings ranged from 650 kWh per m² solar collector to 900 kWh per m² solar collector.

Thür et al. (2006) showed that the energy savings of solar heating systems are strongly influenced by the efficiency of the energy system prior to installation of the solar heating system. Especially the efficiency during the summer period is of great importance.

Furbo et al. (2004) showed that the utilizations of natural gas and oil in the summer and in periods with low heat demands are very low for new natural gas boilers and oil fired burners in one family houses without solar heating systems. A condensing and a non condensing natural gas boiler as well as a non condensing oil fired burner were included in the investigations. In spite of high yearly utilizations of natural gas and oil between 80% and 95%, the utilization decreased to values between 50% and 80% for the boilers/burner in the summer months, May-September. In the five summer months, the energy loss defined as the oil/natural gas consumption minus the space heating demand minus the hot water consumption was about 1000 kWh for the oil fired burner and for the non condensing natural gas boiler, and about 500 kWh for the condensing natural gas boiler. These relatively high energy quantities can easily be saved by well performing solar heating systems. Consequently, the potential for high energy savings for solar heating systems in houses heated by natural gas or oil is good.

This paper presents investigations of energy savings for 21 new solar heating systems in one family houses. The energy savings have been determined by means of information on the energy consumption of the houses before and after installation of the solar heating systems.

2. Investigated solar heating systems

Department of Civil Engineering, Technical University of Denmark, interested solar heating installers and the companies Velux Denmark A/S, Sonnenkraft Scandinavia A/S and Batec Solvarme A/S found 21 house owners who installed a solar heating system in their one family houses. The solar heating systems, of which 9 are marketed by Velux Denmark A/S, 8 by Sonnenkraft Scandinavia A/S and 4 by Batec Solvarme A/S, were installed in the period August, 2008 - February, 2010. The houses have different sizes, insulation standards and energy systems. 13 houses have natural gas boilers, 3 houses have oil fired burners, 3 houses are electrically heated and 2 houses are heated by district heating. Further, 5 of the houses have a second auxiliary energy supply system in the form of a heat pump, a pellet boiler or a woodburning stove. The only changes of the houses were the installation of the solar heating systems. 11 houses are located in Zealand, 6 in Jutland, 3 on Funen and 1 on Bornholm.

6 SDHW systems and 15 solar combi systems are included in the investigations. 5 of the solar combi systems are based on prefabricated energy units including a natural gas boiler and a heat storage. The other 16 solar heating systems are installed in houses without any change of the existing energy system. The solar heating systems have different collector areas in the interval from 1.83 m² to 9.28 m². The average solar collector area of the 21 solar heating systems is 5.96 m². 2 of the systems are based on evacuated tubular solar collectors and 19 systems have flat plate collectors. The heat storage volumes vary between 200 l and 800 l.

The most important data for the 21 solar heating systems are given in Table 1 and Table 2. DMI's (Denmark's Meteorological Institute's) climate stations, located closest to each of the solar heating systems, are given as well. All the SDHW systems are based on flat plate solar collectors. The solar combi systems in Årslev and Gørløse are based on evacuated tubular solar collectors. All other solar combi systems are based on flat plate solar collectors. The house owners informed Department of Civil Engineering about the energy consumption of the houses before and after installation of the solar heating systems.

Tab. 1: Data for the 6 investigated SDHW systems

Location	Manufacturer	Solar collector area, m²	Tank volume, l	Collector orientation/tilt	Number of inhabitants	Auxiliary energy supply system	Climate station
Jægerspris	Velux	3.65	200	South west/45°	2	Oil fired burner	Hillerød
Kerteminde	Batec	4.38	280	South/45°	3	Natural gas boiler and woodburning stove	Odense
Tilst	Velux	1.83	200	South/30°	2	Electric heating and heat pump	Aarhus
Højbjerg	Sonnenkraft	6.61	400	East/20°	5	Electric heating	Aarhus
Morud	Velux	4.30	300	South/21°	4	Natural gas boiler	Odense
Humlebæk	Velux	4.30	300	South west/60°	2	Electric heating and woodburning stove	Sjælsmark

Tab. 2: Data for the 15 investigated solar combi systems

Location	Manufacturer	Solar collector area, m²	Tank volume, l	Collector orientation/tilt	Number of inhabitants	Auxiliary energy supply system	Climate station
Hørsholm	Sonnenkraft	3.23	255	South/45°	3	Solar tank/natural gas boiler unit and woodburning stove	Sjælsmark
Charlottenlund	Sonnenkraft	6.63	500	South east/40°	2	Solar tank/natural gas boiler unit	Sjælsmark
Årslev	Sonnenkraft	6.46	500	South south west/45°	4	Natural gas boiler	Odense
Gørløse	Sonnenkraft	8.81	800	East and west/45°	3	District heating	Hillerød
Birkerød	Sonnenkraft	4.64	350	South/30°	2	Solar tank/natural gas boiler unit	Sjælsmark
Glostrup	Batec	6.57	200	South/30°	1	Natural gas boiler	Copenhagen
Svinninge	Batec	9.00	280	South/30°	4	Natural gas boiler	Nykøbing Sj.
Sulsted	Sonnenkraft	4.66	300	South/35°	2	Solar tank/natural gas boiler unit	Aalborg
Humlebæk	Batec	8.76	280	South/15°	2	Oil fired burner	Sjælsmark
Rønne	Velux	5.76	400	South/45°	2	Oil fired burner and pellet boiler	Rønne
Dyssegård	Velux	6.46	400	South/30°	5	Natural gas boiler	Copenhagen
Hellerup	Sonnenkraft	9.28	500	South/45°	4	Natural gas boiler	Copenhagen
Haderslev	Velux	6.46	300	South/30°	5	Natural gas boiler	Åbenrå
Vinderup	Velux	6.46	400	South/35°	4	District heating	Holstebro
Horsens	Velux	6.93	400	West and south/25°	5	Solar tank/natural gas boiler unit	Horsens

3. Analyses method

The heat demands and thereby the energy consumptions of the houses are first of all influenced by the weather. Especially the number of degree days is of vital importance for the energy consumption. The monthly number of degree days for the climate station located close to the solar heating system in question available on DMI's homepage http://www.dmi.dk/dmi/index/danmark/oversigter/graddage.htm (2011) is therefore used when determining the energy savings of the solar heating system.

The connection between the yearly number of degree days and the yearly energy consumption for the house is for each house determined, based on the monthly number of degree days and on the information on the energy consumption from the house owners, for a number of years before the solar heating system was installed. Based on this connection and the yearly number of degree days, the energy consumption of the house is determined for one year in the period 2009-2010 assuming that the solar heating system is not installed. Since the yearly energy consumption of the house with the solar heating system is known, the yearly energy savings of the solar heating system is found as the difference between the two energy consumptions.

In the following, an example on how to determine the energy savings for the solar heating system in Højbjerg is given. The house is electrically heated as it appears from Table 1. The solar heating system was installed in August 2009. Yearly electricity consumptions for the house during 3 years before the installation of the solar heating system and during 1 year after installation of the solar heating system as well as the number of degree days at the climate station of Aarhus are given in Table 3.

Tab. 3: Electricity consumption and number of degree days for the house in Højbjerg

Period	Electricity consumption	Degree days
October'06-September'07	20660 kWh	2650 K·days
October'07-September'08	21701 kWh	2934 K·days
October'08-September'09	21884 kWh	3089 K·days
October'09-September'10	19454 kWh	3476 K·days

Figure 1 shows the yearly electricity consumption as a function of the yearly number of degree days for the house in Højbjerg with and without the solar heating system. Based on the figure, it is estimated that the electricity consumption in the period October'09 – September'10 would have been about 23500 kWh without the solar heating system. The electricity consumption was 19454 kWh. This corresponds to yearly energy savings for the solar heating system of: 23500 - 19454 kWh, or to about 610 kWh per m² solar collector per year.

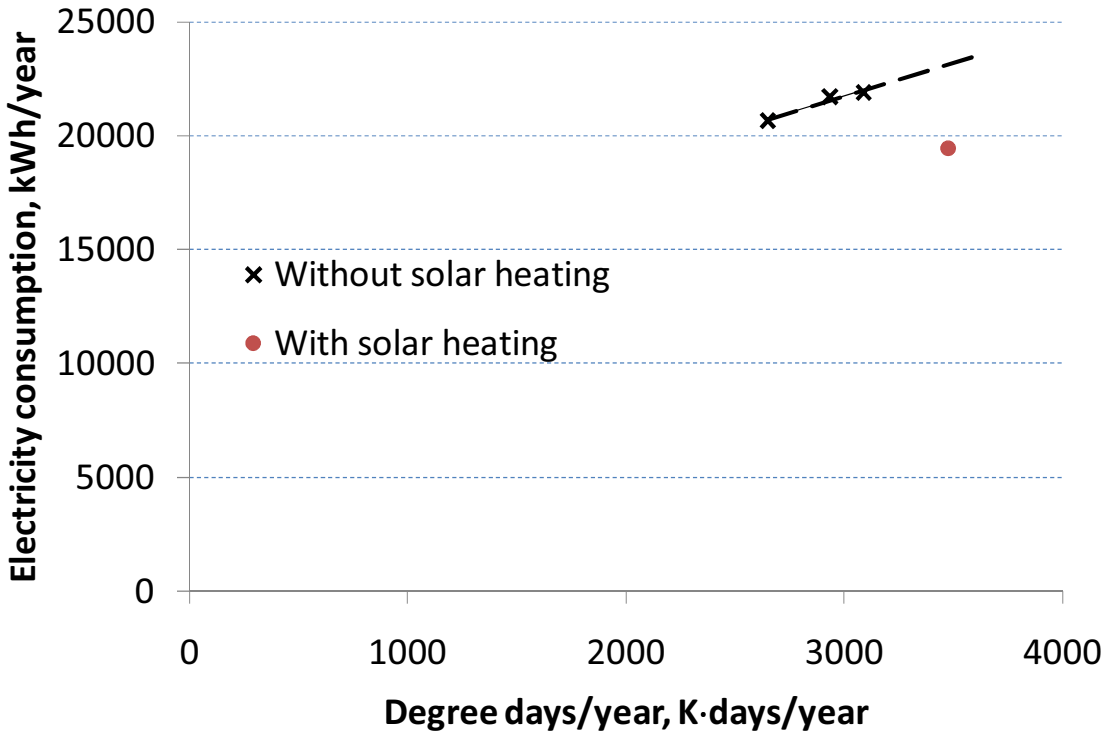

Fig. 1: Energy consumption as function of degree days for the house in Højbjerg with and without the solar heating system.

The main reasons for the high energy savings are most likely a high heat loss from the existing hot water tank and a high heat loss of the circulation pipe covered by the solar heating system.

As it appears from Tables 1 and 2, solar heating systems with different auxiliary energy supply systems are included in the investigations. The energy consumptions are given in m^3 natural gas, l oil, kg pellets, kg wooden briquettes, kg wood, m^3 wood, kWh electricity or kWh district heating. The determination of energy savings for the solar heating systems in kWh is based on:

- 11.08 kWh per m^3 natural gas
- 9.89 kWh per l oil
- 4.90 kWh per kg pellet
- 4.90 kWh per kg wooden briquettes
- 4.04 kWh kg wood or 2025 kWh per m^3 wood

The values for pellets, wooden briquettes and wood are uncertain, since the moisture content of the wood is influencing the values. However, it is estimated that the values are reasonable. The values for natural gas and oil are more certain.

The method described above is used when determining the energy savings for all the 21 solar heating systems. The total energy consumptions of the houses including the electricity consumption are considered, even for the houses which are not electrically heated. In this way, the electricity consumption related to the solar heating system, to the auxiliary energy supply system and to the energy system of the house before installation of the solar heating system, is considered.

The method is, depending on the information from the house owners, for some solar heating systems used with yearly energy consumptions and yearly numbers of degree days, for other solar heating systems with monthly energy consumptions and monthly numbers of degree days. The yearly energy savings of the solar heating systems are determined for 12 months in the period January, 2009 – December, 2010. The period is depending on the information from the house owners. It is estimated that the yearly energy savings of the solar heating systems are determined with an accuracy of about 10%.

4. Energy savings for solar heating systems

The yearly energy savings for the 21 solar heating systems appear from Table 4. Both the total yearly energy savings and the yearly energy savings per m^2 solar collector for the solar heating systems are given.

The yearly energy savings for the 21 solar heating systems vary between 1300 kWh and 9700 kWh.

The yearly energy savings per m² solar collector vary between 300 kWh per m² solar collector and 1300 kWh per m² solar collector for the solar heating systems installed in the houses where the existing energy system is used as the auxiliary energy supply system for the solar heating system.

The yearly energy savings per m² solar collector vary between 790 kWh per m² solar collector and 2090 kWh per m² solar collector for the solar heating systems based on energy units with a natural gas boiler and a solar heat storage.

Tab. 4: Yearly energy savings for the 21 solar heating systems

Location	Manufacturer	Solar collector area m²	Back up energy system	Typical yearly energy consumption before installation of solar heating system kWh	Yearly energy savings kWh	kWh/m²
Jægerspris	Velux	3.65	Oil fired burner	18000	3000	820
Kerteminde	Batec	4.38	Natural gas boiler and woodburning stove	18000	1300	300
Tilst	Velux	1.83	Electric heating and heat pump	6000	1400	770
Højbjerg	Sonnenkraft	6.61	Electric heating	22000	4100	620
Morud	Velux	4.30	Natural gas boiler	15000	2900	670
Humlebæk	Velux	4.30	Electric heating and woodburning stove	15000	2600	600
Hørsholm	Sonnenkraft	3.23	Solar tank/natural gas boiler unit and woodburning stove	44000	6700	2070
Charlotten-lund	Sonnenkraft	6.63	Solar tank/natural gas boiler unit	34000	6900	1040
Årslev	Sonnenkraft	6.46	Natural gas boiler	20000	2000	310
Gørløse	Sonnenkraft	8.81	District heating	17000	6500	740
Birkerød	Sonnenkraft	4.64	Solar tank/natural gas boiler unit	27000	9700	2090
Glostrup	Batec	6.57	Natural gas boiler	15000	3000	460
Svinninge	Batec	9.00	Natural gas boiler	21000	7000	780
Sulsted	Sonnenkraft	4.66	Solar tank/natural gas boiler unit	24000	7400	1590
Humlebæk	Batec	8.76	Oil fired burner	35000	4000	460
Rønne	Velux	5.76	Oil fired burner and pellet boiler	29000	6800	1180
Dyssegård	Velux	6.46	Natural gas boiler	36000	8400	1300
Hellerup	Sonnenkraft	9.28	Natural gas boiler	55000	6000	650
Haderslev	Velux	6.46	Natural gas boiler	20000	3600	560
Vinderup	Velux	6.46	District heating	30000	3100	480
Horsens	Velux	6.93	Solar tank/natural gas boiler unit	23000	5500	790

5. Summary

The yearly energy savings of the 16 solar heating systems installed in houses without any change of the existing energy system vary between 300 kWh per m² solar collector and 1300 kWh per m² solar collector. The average yearly energy savings are about 670 kWh per m² solar collector for the 16 solar heating systems. The energy savings per m² solar collector are not influenced by the type of solar heating system, the auxiliary energy supply system, the solar collector manufacturer, the solar collector area, the solar collector type, the

solar collector tilt and azimuth. Further, the energy savings per m² solar collector are not influenced by the energy consumption and location of the house.

The yearly energy savings of the 5 solar heating systems based on prefabricated energy units including a natural gas boiler and a heat storage vary between 790 kWh per m² solar collector and 2090 kWh per m² solar collector. The average yearly energy savings are about 1520 kWh per m² solar collector for these 5 solar heating systems.

The yearly energy savings for solar heating systems in one family houses are very high, between 300 kWh per m² solar collector and 2090 kWh per m² solar collector. In houses where the existing energy systems are used as the auxiliary energy supply systems for the solar heating systems typical energy savings for the solar heating systems vary between 500 kWh per m² solar collector and 800 kWh per m² solar collector. For solar heating systems based on a prefabricated energy unit including a natural gas boiler and a heat storage, typical energy savings for the solar heating systems vary between 1000 kWh per m² solar collector and 2000 kWh per m² solar collector.

6. Conclusions

Energy savings for 21 of new solar heating systems in one family houses have been determined by means of information on the energy consumption of the houses before and after installation of the solar heating systems. The houses are placed at different locations in Denmark.

The investigated solar heating systems are marketed by Velux Danmark A/S, Sonnnenkraft Scandinavia A/S and Batec Solvarme A/S. Solar domestic hot water systems as well as solar combi systems are included in the investigations. The houses have different auxiliary energy supply systems: Natural gas boilers, oil fired burners, electrical heating and district heating. Some of the houses have a second auxiliary energy supply system. The collector areas vary from 1.83 m² to 9.28 m².

Five of the solar heating systems are based on prefabricated energy units with a new integrated natural gas boiler and a heat storage for the solar heating system. The existing energy systems in the houses are, for 16 of the houses, used as the auxiliary energy systems for the solar heating systems.

The yearly energy savings for the 5 houses with solar heating systems based on energy units including a new natural gas boiler vary from 790 kWh per m² solar collector to 2090 kWh per m² solar collector. The average yearly energy savings are about 1520 kWh per m² solar collector for these solar heating systems.

The yearly energy savings for the 16 houses where the only change is the installation of the solar heating system vary from 300 kWh per m² solar collector to 1300 kWh per m² solar collector. The average yearly energy savings are about 670 kWh per m² solar collector for these solar heating systems. The energy savings per m² solar collector for these systems are not influenced by the solar heating system type, the company marketing the system, the auxiliary energy supply system, the collector area, the collector tilt, the collector azimuth, the energy consumption of the house or the location of the house.

That is, yearly energy savings for new solar heating systems in one family houses are high, ranging from 300 kWh per m² solar collector to 2090 kWh per m² solar collector. If the existing energy system is used as the back up energy system for the solar heating system, typical yearly energy savings vary from 500 kWh per m² solar collector to 800 kWh per m² solar collector. For solar heating systems with an energy unit including a new natural gas boiler, typical yearly energy savings vary from 1000 kWh per m² solar collector to 2000 kWh per m² solar collector.

The yearly energy savings for the solar heating systems are much higher than the solar heat produced by the solar collectors and higher than normally anticipated.

7. References

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