SOLAR ACTIVE HOUSES: BUILDINGS WITH A SOLAR THERMAL FRACTION OF AT LEAST 50 % AS THE BUILDING STANDARD OF THE FUTURE

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1. Introduction

By far most of the energy consumption in private households in Germany and Middle Europe is used for space heating. Regarding the German government's aim to reduce the energy consumption in the private sector in combination with an increasing share of renewable energy sources, solar thermal heated houses become more and more attractive. Additionally the European Solar Thermal Technology Panel (ESTTP) of the European Technology Platform on Renewable Heating and Cooling (RHC-TP) and the corresponding German Solar Thermal Technology Platform (DSTTP) consider solar thermal heated houses as a key element for a low-cost and CO_2-neutral heating energy supply in the future. Therefore the development of houses covering far more than 50 % of their overall heat demand with solar thermal energy comes into the focus. Such houses are called "Solar Active Houses". The main components of a Solar Active House, with regard to single-family houses, are a thermal solar collector with an area of 30 m² to 50 m² and a (seasonal) hot water store with a volume of 5 m³ to 15 m³.

Due to the fact that Solar Active Houses are relatively new on the building market compared to "conventional" buildings, a scientific basis for the technical design as well as an assessment of the energy concept of those buildings is still missing. These aspects are both elaborated in the project "HeizSolar" (Evaluation and optimisation by simulation of heating supply concepts for living buildings, equipped with solar thermal covering 50 % to 100 % of their total heat demand, and comparison with other CO_2 reduced heat supply concepts.), financed by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), and conducted by the Fraunhofer Institute for Solar Energy Systems (ISE) in cooperation with Solar- und Wärmetechnik Stuttgart (SWT), the Ilmenau University of Technology and the Sonnenhaus Institute e.V.. The first key element of the project is a market study of currently available building concepts with low energy demand and high solar thermal fractions. The second key element is a detailed monitoring of nine existing Solar Active Houses in order to get a deep insight of the energy fluxes and energy demands of various types of those buildings. With the monitoring data the primary energy demand can be calculated and the energy concept of Solar Active Houses can be evaluated and compared to other building concepts. Furthermore the data can be used for the validation of detailed numerical simulation models for TRNSYS being developed for different types of Solar Active Houses as a basis for a simulation study and the identification of optimal system configurations.

2. The Concept of Solar Active Houses

The heating concept of conventional buildings in most countries of the world is based on using fossil fuels for domestic hot water preparation and space heating. The implementation of a solar thermal system for domestic hot water preparation and / or space heating in such buildings results in a solar assisted fossil fuel based heating concept.

In contrast, the concept of a Solar Active House includes a powerful solar thermal system covering at least 50 % of the total heat demand required for domestic hot water preparation and space heating. Depending on the solar fraction, an additional fossil or wood fired heat source is implemented. This concept represents a fossil/wood fuel assisted solar thermal heating concept. Both from a technical and a psychological aspect this is an important step, since now the sun provides the dominating part of heat.

2.1 General

In order to cover a major part of the heat demand with solar energy, the entire building must obviously be planned and constructed "solar friendly". Beginning with the orientation, all Solar Active Houses are facing to the equator's direction. Since up to now nearly all Solar Active Houses have been built in the northern hemisphere, they are all facing south. With an increased share of glazing at the south side - compared to conventional buildings - passive solar gains become an important factor in decreasing the heat demand. For the provision of overheating during the summer months, appropriated shading mechanisms have to be installed.

Furthermore the thermal insulation of these buildings is optimised and the overall heat loss coefficient (HT') is below 0.28 W/(m²K) for new built and below 0.4 W/(m²K) for refurbished[1] buildings. The space heating, which is mandatory in central Europe, is realized as a low temperature heating systems such as floor or wall heating.

Additionally the collector field is relatively large and collector areas between 30 m² and 50 m² for single-family houses are common. For increasing the solar thermal gains in wintertime, the inclination angle of the collector field should be between 60° and 85°. Another positive aspect of this steep angle is the decrease of periods of stagnation during summertime.

The core component of a Solar Active House is the heat store. The store has to transfer the surplus energy from times with higher solar radiation to times with low or even without solar radiation. Depending on its size, the storage period varies from a few weeks to several months and has therefore often a seasonal character. Using water as heat storage medium the size for such a store for single-family applications is typically between 5 m³ and 15 m³.

Figure 1 shows a picture of a Solar Active House. The open façade to the south as well as the large steeply inclined collector field is visible. In Figure 2 a schematic illustration of a Solar Active House is given. The intersection of the building shows the relatively high and slim store.

Fig. 1: Example for a Solar Active House,
Source: Sonnenhaus Institut e.V.

[1] Requirements of the Sonnenhaus Institute e.V.

Fig. 2: Schematic illustration of a Solar Active House,
Source: Sonnenhaus Institut e.V.

2.2 Heating concepts of Solar Active Houses

For the project "HeizSolar" nine representative Solar Active Houses have been selected for a long-term monitoring. The nine buildings have been chosen according to different requirements like the coverage of various solar fractions or different typical German climate conditions. Besides one enlarged and refurbished existing building, all monitored houses are newly built.

Most of the selected buildings have implemented a backup heating system based on wood (pellets, wood chips, split logs). But in general it is also possible to equip Solar Active Houses with backup heating systems using other energy sources such as e.g. heat pumps. Table 1 shows the nine Solar Active Houses; seven single-family houses (SFH) and two multifamily houses (MFH), selected for the investigation within the HeizSolar project.

Tab. 1: Solar Active Houses selected for long-term monitoring and further investigation

Building		**System technology**				
type – total floor area [m²]	**HT'** [W/(m²K)]	**Collector area** [m²]	**Store volume** [m³]	f_{sol} [%]	**Backup heating system**	**Ventilation with/without heat recovery**
SFH – 202	0,30	31	7,1	75	(tile) stove	without
MFH – 549	0,28	62	15,1	60	wood gas boiler	with
SFH – 300	0,16	112	42,8	100	without	with
MFH – 800	unknown	127	47	unknown	pellets boiler	without
SFH – 232	0,34	34	2	70	pellets oven	with
SFH – 403	0,27	48	9,3	50	pellets boiler	without
SFH – 563	unknown	36	4	unknown	wood chips boiler	with
SFH - unknown	unknown	unknown	unknown	60	unknown	unknown
SFH – 250	unknown	68	11	82	(tile) stove	unknown

Some of the buildings are still in the construction phase; therefore not all data is available up to now or is only based on design figures.

Most of the Solar Active Houses are using a large store to achieve a high solar fraction. Only the single-family house with 232 m² total floor area has a slightly different concept. With a 2 m³ store, this building is designed to achieve a solar fraction of 70 %. This is due to high passive gains and a high efficient pellets oven, which is placed in the living room.

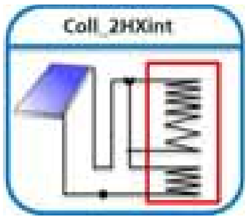
Furthermore one Solar Active House does not have a backup heating system at all and consequently the solar fraction is 100 %. It is obvious that in this case both a large seasonal heat store and a large collector area are necessary. Additionally this building concept shows the lowest of all heat loss coefficients.

2.3 Description of the system design:

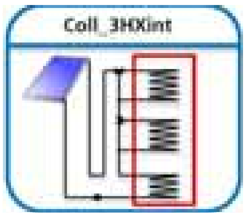
The following section introduces the different approaches for the integration of the heat sources (collector field, backup heating system) and the heat sinks (space heating, hot water preparation) into the thermal system providing domestic hot water and space heating.

Collector field:

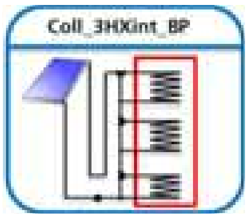
- Two internal heat exchangers:
  The heat transfer medium flows depending on its temperature level through both heat exchangers or it bypasses the upper one and transfers the heat only to the bottom of store. Hence the heat transfer medium returns to the collector at the lowest possible temperature level to achieve the maximum possible efficiency of the collector.



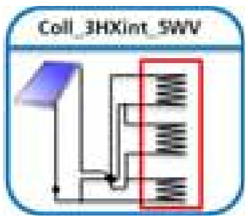
- Three internal heat exchangers:
  Similar to the configuration with two internal heat exchangers, but thermal stratification can be realized more precisely according to the respective temperature levels of the heat transfer medium.



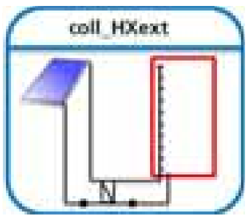
- Three internal heat exchangers with bypass:
  Similar to the configuration with three internal heat exchangers, but the third and lowest heat exchanger can also be bypassed.



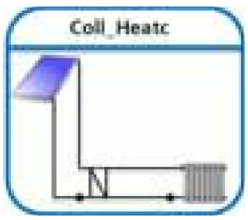
- Three internal heat exchangers with a five-way valve:
  Depending on the temperature of the heat transfer medium the five-way valve controls the charging of the store. The same hydraulic connections are possible as with the configurations mentioned above.



- One external heat exchanger combined with an internal stratification device:
  The heat transfer medium heats up the storage medium via an external heat exchanger. Afterwards the storage water is fed into the store through an internal stratification system according to its respective temperature level.

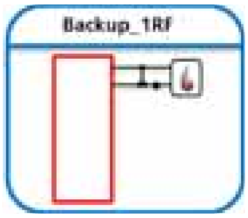


- Direct heat transfer to the space heating loop via an external heat exchanger:
  As an additional hydraulic connection this configuration allows for a direct heating of the heat distribution circuit (space heating) via an external heat exchanger. Hence, the store is bypassed in this configuration.

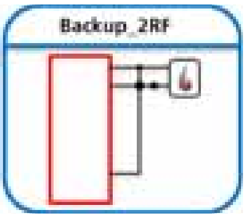


Backup heating system:

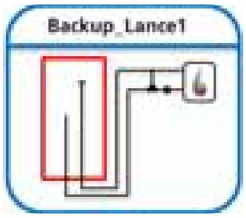
- One store outlet:
  The backup heating system is heating the upper part of the store. One return line and a return flow boost are implemented.



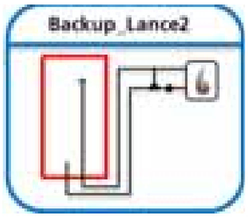
- Two store outlets:
  Additionally a second store outlet is implemented so that the backup heating system can heat up the entire store. This concept is used if the capacity of the store is relatively small compared to the maximum heat demand or to that delivered by the boiler. In this context a typical application is the combination with a boiler of which the delivered heat can hardly not be controlled, such as a wood split log boiler.



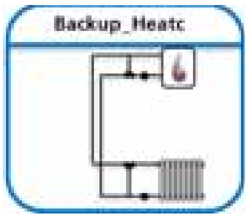
- Two lances (store in- and outlet):
  The heated medium is injected into the store via an injection lance at the upper part of the store; the outlet is also realized with a lance.



- Two lances (store in- and outlet) entire store
  In contrast to the configuration above the lance for the outlet ends in the bottom of the store. Hence, the backup heating system heats up the entire store.

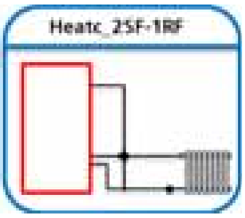


- Direct connection to the space heating:
  The backup heating system heats the space heating circuit directly by omitting the store.

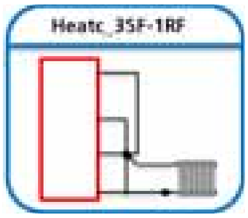


Space heating:

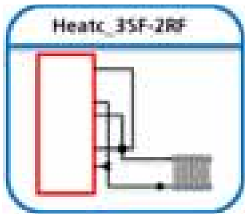
- Two store outlets, one store intlet:
  Depending on the required temperature level of the flow the four-way valve connects the space heating flow line to one of the two outlets of the store. The return flow from space heating enters the store at the bottom.



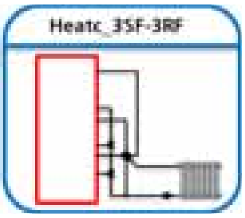
- Three store outlets, one store inlet:
  Depending on the required temperature level of the flow the five-way valve connects the space heating flow line to one of the three outlets of the store. The return flow from space heating enters the store at the bottom.



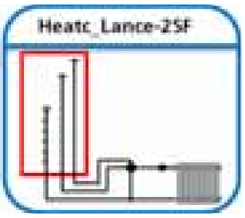
- Three store outlets, two store inlets:
  Flow line adjustment is realized like above. Depending on the temperature level of the return line the three-way valve connects the return line to the inlet at the corresponding height of the store.



- Three store outlets, three store inlets:
  Flow adjustment is realized like above. Depending on the temperature level of the return line the two three-way valves connect the return lines to the inlet at the corresponding height of the store.



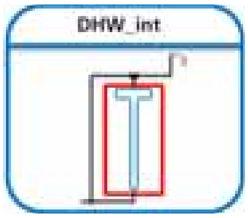
- Two store outlet lances, one stratification system for the inlet:
  Depending on the required temperature level of the flow the four-way valve connects the flow line of the heating system to one of the two store outlet lances. The store inlet is realized via a stratification system.



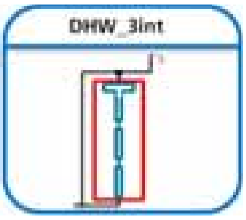
Hot water preparation:

All configurations presented below have the possibility to implement a hot water circulation pipe. For reasons of simplicity this is not illustrated.

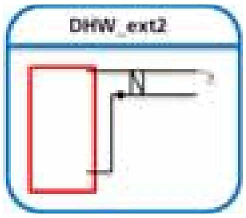
- One Tank-in-tank concept:
  One internal store is implemented inside the main store for hot water preparation. Scald protection is performed with a mixing valve.



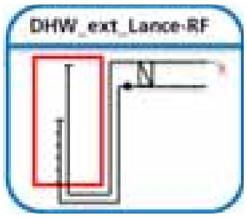
- Three tank-in-tank concept:
  Three serial connected internal hot water stores are implanted inside the main store for hot water preparation. Scald protection is performed with a mixing valve.



- External heat exchanger:
  The hot water is prepared via an external heat exchanger.



- External heat exchanger combined with store outlet lance and stratification system for the store inlet:
  The hot water is prepared via an external heat exchanger. The store outlet is realized via a lance. The return flow enters the store via a stratification system.



All presented system designs are not yet evaluated and therefore their benefit is not proven. This is also a goal of the project HeizSolar using detailed simulation studies to evaluate the several system designs. It is indented to identify those concepts that do have a good performance and additionally are simple and therefore reliable.

3. Measuring concept for the long-term monitoring

The long-term monitoring of the nine Solar Active Houses will be the basis for the scientific understanding of relatively these large solar thermal systems. Additionally the integration and the interaction of the solar thermal system with the building itself will be assessed. The comparison with other heating concepts, both conventional and CO_2-reduced concepts such as passive houses, is a further aim. Moreover the measuring data will be utilized to validate and adjust the simulation models. If optimisation potentials are detected during the long-term monitoring, they will be realized if possible and reasonable or at least used for the further development of the Solar Active House concept.

The basis for the evaluation of the thermal system providing space heating and hot water for the Solar Active Houses is the creation of energy balances of the entire system. The store is the core component and has a dominating influence on the operation mode and the performance of the whole system. Therefore the store has a main focus during the evaluation during the long-term monitoring.

Figure 3 shows a scheme of the measuring concept for the long-term monitoring of a typical Solar Active House. This concept enables a simple calculation of all required energy balances.

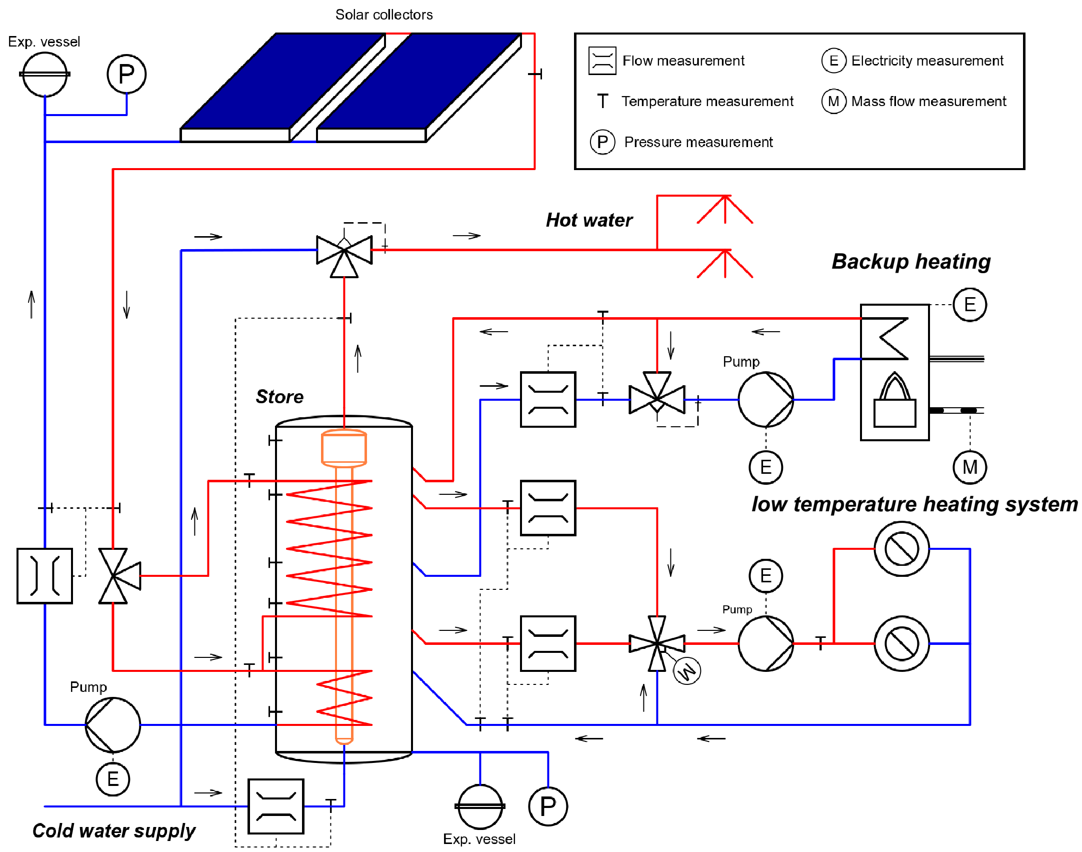


Fig. 3: Schema of the measuring concept for one type of system

The measuring equipment will be described in the following:

Flow measurement: Magnetic inductive flow meters as well as ultrasonic flow meters are used. For calculating energies the flow meters are combined with resistance temperature sensors.

Temperature measurement: Resistance temperature sensors of the type Pt100 are used. For the temperature measurement in the store, available immersion sleeves are used. Unfortunately, some stores are already implemented into the building in such a way that it is not possible to reach the outside wall of the store any more, e.g. the insulation is already installed or the entire store inclusive insulation is integrated into the building and represents one wall of the living room. In these cases the temperatures available from the controller have to be used.

Pressure measurement: The supervision of the pressure both in the collector loop and in the heating circuit allows for evaluating the functionality and the modes of operation like failures and times of stagnation.

Auxiliary energy measurement: The determination of the fuel demand required by the backup heating system and the calculation of the corresponding energy balances is difficult. This is due to used type of fuel, particularly the heating value and humidity of split logs is hardly to characterize. To achieve the highest possible accuracy the following procedure is applied:

- The inhabitants receive wood briquettes whose characteristic data such as the heating value and humidity) were determined before.
- An exemplary combustion is performed for a detailed characterization of the specific boiler/oven.
- The inhabitants determine the amount of used fuel each time they operate the boiler by weighing during the entire long-term measuring period.

Solar radiation measurement: For the determination the incident radiation pyranometers are used (not illustrated in figure 3).

4. TRNSYS simulation models

As another main issue of the HeizSolar project, detailed simulation models for the heating sytems of Solar Active Houses shall be created and adjusted and - if not available - required components should be developed.

In a first step the available models have been assessed and adjusted to the specific needs of Solar Active Houses. Up to now the building standard of a Solar Active House and the solar thermal system are implemented.

After the first measuring period the simulation models will be adjusted again and validated using the measured data of the long-term monitoring.

The studies carried out with these validated simulation models will be used to analyse the interaction between the building and the heating system of Solar Active Houses. Furthermore the provide a basis for the identification of optimised concepts.

5. Building standard of the future

The European Solar Thermal Technology Panel (ESTTP) developed several possibilities to for realizing this future scenario within its “Solar Thermal Vision 2030”. The main vision of the DSTTP and ESTTP is achieving a solar thermal share of 50 % of Europe’s total the heat demand in 2050. Key elements of this context are:

- The Solar Active House becomes the standard building type for newly built houses. It is essential that the solar thermal fraction of this standard house must increase up to 100 %.
- The refurbishment of the existing buildings must change to a solar modernisation. The solar modernisation has to be developed towards the most cost-effective solution and a solar fraction related to the entire heat demand of the building of far more than 50 % has to be achieved.
- For industrial processes, demanding heat on a temperature level of up to 250 °C solar thermal shall become provide a significant contribution
- Solar thermal cooling must become THE standard technology.

Especially the revision of the European Energy Performance of Buildings Directive (EPBD ;2002/91/EG) will require that from 2019 all public buildings and from 2021 all new buildings are realised as “nearly zero energy buildings”. As a concept of these nearly zero energy buildings the Solar Active House concept is reasonable. Solar Active Houses do have a lot of advantages for the occupants:

- Ecological: Entire sustainable heat supply: the heating system changes from a solar assisted fossil heating via a fossil/biomass assisted solar heating to a solar-only heating system.
- Prize guarantee: Solar thermal energy use is independent of the prize development of the energy costs. Therefore on the bases of the initial investment a long-term prize guarantee is given.
- Security of energy supply: The availability of fossil fuels becomes irrelevant.
- Independent: The heat supply is realized as an quasi autarky system; a dependency from prize and supply structures is not given anymore.

Since these factors serve as significant added value, economic aspects take a back seat. It is expected that in medium-term, the pricing pressure on the market for Solar Active Houses will be much lower that in other solar thermal markets such as e.g. for solar domestic hot water systems.

6. Conclusion and outlook

Solar Active Houses, covering by far more than 50 % of the thermal energy demand by solar, are alreay available on the market. Up to now more than 800 buildings are realized so far. These Solar Active Houses were planned and constructed only by a few architects, designers and plumbers on the basis of experience. However, since the concept of Solar Active Houses becomes more and more attractive as a future building standard, a scientific basis for this concept has become mandatory.

This paper has presented the Solar Active House concept in detail. Furthermore the measuring concept for the long-term monitoring performed within the project German HeizSolar was explained. The long-term monitoring will be started in autumn 2011 and cover the heating period 2011/2012.

A comparison with other building concepts available on the market is performed within the project. The aim is to compare those concepts with regard to primary energy demand, comfort for the inhabitant, investment and operation costs.

Currently, simulation models are developed for a detailed assessment and optimization of the building and the heating system. Particularly the store, designed partly as a seasonal heat store, is investigated in detail.

The results of the project HeizSolar will serve as a scientific basis for the optimisation and standardization of reliable heat supply concepts for solar thermal heated buildings with high solar fractions.

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Further information can be found on the project's website:

Internet: www.heizsolar.de

8. Acknowledgement

The Project HeizSolar is funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit BMU). The authors gratefully thank for the support and carry the full responsibility of the content of this publication.