Available online at www.sciencedirect.com

ScienceDirect

Solar Energy 131 (2016) 1–20

SOLAR ENERGY

www.elsevier.com/locate/solener

# Direct integration of solar heat into the space heating circuit

J. Glembin *, T. Haselhorst, J. Steinweg, S. Föste, G. Rockendorf

*Institut für Solarenergieforschung Hameln (ISFH), Am Ohrberg 1, D-31860 Emmerthal, Germany*

Received 10 November 2015; received in revised form 15 February 2016; accepted 16 February 2016

Communicated by: Associate Editor Yanjun Dai

## Abstract

Solar heat in solar thermal combisystems is usually used via a buffer storage. Alternatively, the solar collectors may be connected directly to the space heating circuit in order to store the heat in the building itself. Such a direct solar integration is investigated within system simulations for different layouts and heating elements. The operation of these systems requires a control strategy, which distributes the solar heat optimally between the potential heat sinks leading to the lowest overall energy consumption. This way a solar fraction may be achieved which is comparable to usual combisystems equipped with a three times larger buffer storage. A prototype of one of the investigated heating concepts within a single family house proofs the functionality of the system concept and the high solar yield, particularly at low radiation levels. The direct solar heating increases the solar fraction of combisystems significantly or alternatively decreases the necessary storage volume considerably if a certain system performance is desired.

*Keywords:* Solar combisystems; Direct solar heating; Floor heating; Thermal activation; Buffer storage; System simulations

## 1. Introduction and literature review

In the building sector, solar thermal energy is mainly used for hot water preparation, space heating and rarely space cooling. Currently, solar domestic hot water systems still dominate the market. This technology is relatively mature and cost-competitive with systems based on other energy sources. Compared to that, active solar heating is realized less frequently having only a small contribution to the overall space heat demand. However, several energy studies see a great potential and predict a strong market growth for solar thermal combisystems, which is the combination of solar heating and domestic hot water preparation.

In a study for the European Solar Thermal Industry Federation (ESTIF) Weiss and Biermayr (2009) determine the potential of the solar heat market in the countries of the European EU 27. They predict a contribution of solar heat to the low temperature heat demand of 1–4% in 2020 and 4–15% in 2030 depending on the scenario. In their opinion, such a development is only possible if the future solar thermal market development focusses on combisystems in northern and central Europe and additionally on solar cooling in southern Europe.

On the global level, the technology roadmap of the International Energy Agency IEA (2012) predicts an annual growth rate of 7% for solar hot water and space heating leading 2050 to a share of 25% in domestic water heating and 7% in space heating. For the latter, good conditions are especially seen at middle or high latitudes with relatively high solar radiation during the transition periods and a significant heat demand at that time.

---

* Corresponding author. Tel.: +49 5151 999647; fax: +49 5151 999600.
*E-mail address:* j.glembin@isfh.de (J. Glembin).

http://dx.doi.org/10.1016/j.solener.2016.02.032
0038-092X/

## Nomenclature

| | |
|---|---|
| $a_1$ | heat loss coefficient, independent of temperature (W/m$^2$ K) |
| $a_2$ | heat loss coefficient, depending on temperature (W/m$^2$ K$^2$) |
| $b_0$ | factor for calculation of incidence angle modifier (–) |
| $b_1$ | heat loss coefficient of unglazed collector (W/m$^2$ K) |
| $b_2$ | wind dependency of heat loss coefficient $b_1$ (J/m$^3$ K) |
| $b_u$ | wind dependency of conversion factor (s/m) |
| $c_p$ | specific heat capacity (W h/kg K) |
| $\Delta\vartheta$ | temperature difference (K) |
| $\eta$ | efficiency (–) |
| $\eta_0$ | conversion factor (–) |
| $f_{\text{Sol}}$ | solar fraction (–) |
| $H_S$ | upper calorific value (kW h/kg) |
| $I$ | solar irradiance (W/m$^2$) |
| $k_\theta$ | incidence angle modifier (–) |
| $m$ | mass (kg) |
| $\dot{m}$ | mass flow (kg/h) |
| $Q$ | energy amount (W h) |
| $\dot{Q}$ | heat flux (W/m$^2$) |
| $\upsilon$ | temperature (°C) |
| $\theta$ | incidence angle (°) |
| $W_{\text{el}}$ | electricity consumption (kW h) |

*Subscripts*

| | |
|---|---|
| Aux | auxiliary |
| Amb | ambient |
| C/Coll | collector |
| Calc | calculated |
| Corr | correction |
| Diff | diffuse |
| Direct | dir |
| COP | coefficient of performance |
| FH | floor heating |
| GHE | ground heat exchanger |
| IEA | international energy agency |
| IAM | incidence angle modifier |
| HP | heat pump |
| Meas | measured |
| Rad | radiator |
| SIG | signal |
| SHC | solar heating and cooling program |
| SPF | seasonal performance factor |
| St | storage |
| Stag | stagnation |
| TABS | thermally activated buildings system |
| TA | thermal activation |

New building concepts with a low energy demand and/or a high share of renewable energies often contain solar thermal combisystems with high solar fractions. Several authors analyze such systems focusing on the possible contribution of solar heat in this sector. Leckner and Zmeureanu (2011) investigated the life cycle cost for net zero energy buildings equipped with solar combisystems in Canada, Ampatzi et al. (2013) calculated the possible contribution of solar heat for dwellings in Wales and Tsalikis and Martinopoulos (2015) investigated the potential of solar heat in net zero energy buildings in Greece.

System design and dimensioning of solar combisystems is a long-term topic within research and development. Numerous system variants are developed and sold over the world. Due to the mismatch of solar radiation and the heat demand of buildings the storage tank is one of the key components in these systems. Many research activities concentrate on solar combisystems with a central water buffer tank used for storing the solar heat. This is the case for the combisystems used by Jordan and Vajen (2001) to determine the impact of the hot water profile and by Bales and Persson (2003) to find adequate control methods for fresh water modules. Likewise, the analytical model used by Lund (2005) to find dimensioning rules for solar combisystems bases on the same concept.

An extensive investigation of solar thermal combisystems was done within the IEA SHC Task 26 (Weiss et al., 2003). 21 combisystems in the market of 2002 had been identified, categorized and nine of them analyzed more in detail in system simulations. Characteristic for most of the systems is a buffer storage for space heating. This storage is either heated by solar heat alone or additionally by an auxiliary heater. Exceptions are two direct solar floor systems in France with no buffer storage and a direct connection between solar collector and the floor heating system. This kind of system, analyzed by Chèze and Papillon (2002), reaches comparatively high energy savings due to high collector yields and annual boiler efficiencies.

The realization of higher solar fractions by increasing the storage capacity evolved to one of the main tasks in the further development of combisystems. The participants of IEA SHC Task 32 (Hadorn, 2005) analyzed several combisystems in the energetic, economic and ecological performance focusing on the storage as the central component in the system. Besides water, other materials as phase change or thermochemical materials had been developed and evaluated with the conclusion that there is no significant improvement of the analyzed materials compared to a water store. The evaluation of the different storage concepts bases on TRNSYS simulations of a reference combisystem with a fossil fuel boiler and a central combi storage delivering its heat to space heating and an external fresh water station. Several authors used this reference