Pilot Plant of a Solar Thermal Energy Façade for Commercial and Industrial Buildings

Roland Heinzen[1*], Claus-Peter Hartmann[2], Elmar Dohmann[3], Klaus Vajen[4], Antonis Mitsakos[1]

[1] FSAVE Solartechnik GmbH, Weserstr. 9, 34125 Kassel, Germany

[2] Heinrich LAMPARTER Stahlbau GmbH & Co. KG, Leipzigerstr. 12-18, 34260 Kaufungen, Germany

[3] ENERGY GLAS GmbH, Zur Frado 1, 34466 Wolfhagen, Germany

[4] Institute of Thermal Engineering, Kassel University, Kurt-Wolters-Str. 3, 34125 Kassel, Germany

* Corresponding Author: heinzen@fsave.de

Abstract

How can solar thermal systems meet architectural and design needs?

In commercial and industrial buildings solar thermal systems do not have great acceptance among architects and building owners yet. The reasons therefore are the optical appearance of standard collectors and a non holistic approach. It was therefore evident to create an attractive system, including all components, from the façade to the tank, including design and realization. Once this idea was born, the field of realization could easily be expanded not only to new buildings, but as well to energetic improvement purposes of existing buildings. It was obvious that a pilot plant had to be erected, to gain experiences and to improve components.

Thus the set goal was achieved to create an architectural solar thermal façade ready for the market.

1. Introduction

Commercial and industrial buildings represent a large portion of buildings in Europe. The average specific primary energy demand of a commercial building is around 250 kWh/(m² a) [1]. International standards for the efficient use of energy in buildings set the target to 100 kWh/(m² a) of primary energy demand for new buildings [2]. This indicates the huge potential for improvements. Nevertheless, the number of newly constructed buildings is small compared to the existing building stock. The impact by investing into energy efficiency of these buildings is thus considerably higher. Therefore it is necessary to explore efficient ways to improve the energy efficiency of existing buildings in the commercial and industrial sector.

Solutions for energy saving become more and more standard in the private building sector, especially insulation and the utilization of renewable energies, e.g. solar thermal collectors. In private buildings solar thermal systems are widely known in Europe and therefore realized by standard components. At the attempt to introduce them into commercial buildings, many different conditions had to be taken into account:

- **Architectural integration of solar thermal panels into buildings:** commercial or large residential buildings have usually small roof areas compared to the total floor area. Therefore, the potential can be increased by considering the façade, too. Standard solutions for façade collectors especially for large areas above 100 m² are not available on the market and have to be planned individually for a respective project. In addition to that standard components do not match architectural needs. They are not available in different colours and it is not possible to integrate them into façade systems yet.

- **Prevention of work stoppage:** Sanitation of buildings in the commercial and industrial sector is often times accompanied with a loss of production and interruption of work as it usually interferes with the common working infrastructure. The costs caused by interruption of work can be in the same order as the sanitation itself and therefore have to be minimized.
- **Hydraulic integration of the solar thermal system:** hydraulic integration means more than collector technology. It should further take into account heat recovery and create a higher potential for solar yields by heat flux analysis. Consequently, this leads to a high planning effort.
- All measures for a renovation of commercial buildings should show a good **economic amortization**. But exceptions can often be made in order to receive a representative appearance of the building. Hence, the amortization is not the overall economic performance factor as the appearance of a modern and representative building is difficult to quantify. Further more the costs of the solar thermal system can be decreased by removing all costs that are necessary for the hull and appearance anyhow.
- **No standard systems available:** Regarding systems in private buildings, standard components for use on top of roofs are available including components like tanks. They are usually installed by small plumbers. For commercial systems there are neither standard components available nor integrative solutions (from the façade down to the tank).
- **Easy revision:** All components containing solar fluid have to be maintained from outside the building.

These considerations led to the idea of constructing an architectural inspiring façade which combines heat protection, insulation and heat generation, without influencing the activities in the buildings during the renovation phase.

Curtain walls offer a simple and efficient way for energetic renovation of existing buildings in the commercial and industrial sector . This idea was further developed by a consortium of three industry partners[1] located in the Kassel region and Kassel University. A curtain wall concept was developed with a full glass collector, flexible architectural design elements for the façade, flexible heat insulation standards, a hydraulic integration of the collector in the façade and an adjustable peripheral hydraulic unit for heat storage, domestic hot water preparation and space heating support. Figure 1 shows the whole system of the new façade concept and its subelements as well as the responsibilities of the respective partners within the project.

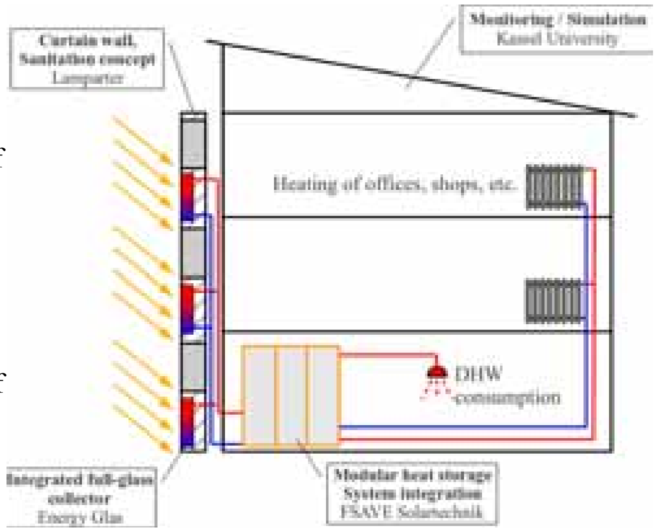

Fig. 1. Scheme of the integrated collector façade in the pilot plant

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[1] Heinrich LAMPARTER Stahlbau GmbH & Co. KG, www.stahl-glas.de
ENERGY GLAS GmbH, www.energy-glas.de
FSAVE Solartechnik GmbH, www.fsave.de

Beside component tests and system simulations, a pilot plant was realized and equipped with sensors to evaluate the energy balance and system performance. This paper gives an overview about the installation of the pilot plant, the collector design and its efficiency curve as well as the overall system design. Finally, the overall system performance will be discussed for the achieved measurement period.

2. Components of the solar thermal energy façade

2.1. Architectural Design

The curtain wall is based on a post and beam steel construction including different functions:

- high-insulated triple-glazed windows provide the offices with day-light and protect and reduce the heat losses of the building during the heating period
- external sun screens to reduce over-heating of the offices during the summer period
- solar collectors are integrated in the façade below the window elements as curtain walling panels
- a narrow duct is used between window and collector elements to integrate the collector piping in the façade
- additional elements are installed at each floor level for the integration of hydraulic or sensor elements

Each function element can be used as design element with different colouring options. While the collector plate in the pilot plant was sputtered, also different colouring is possible by the utilization of special solar lacquer. Figure 2 shows the architectural concept of the façade.

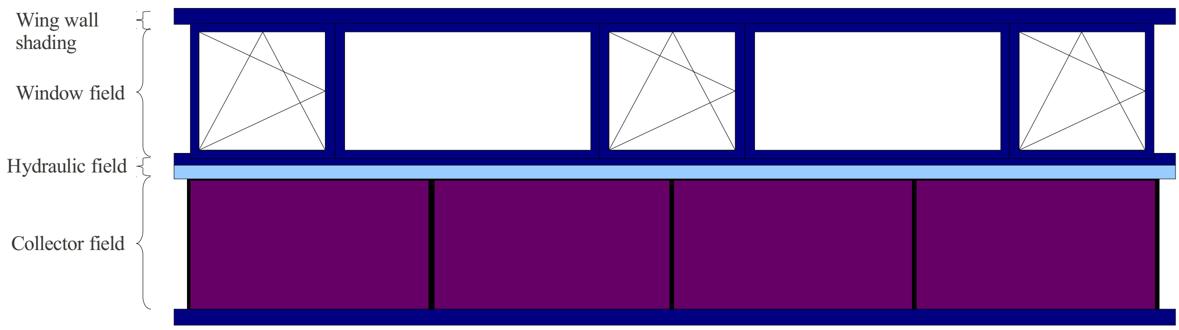
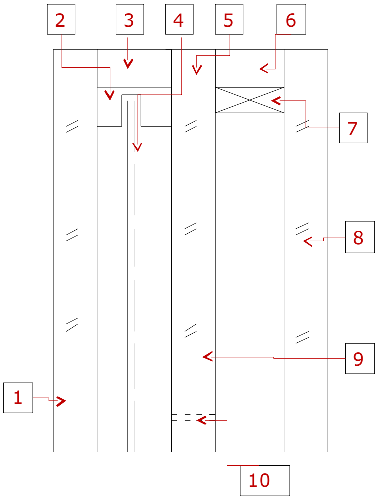


Fig. 2. Function and design elements of the solar thermal energy façade

2.2. Full-glass collector

The company Energy Glas GmbH developed a full-glass flat plate collector with a thickness of about 25 mm. The first prototypes were installed in the investigated solar thermal energy façade with a total aperture area of about 32 m². The prototype is based on a window with triple glazing. The collector plate consists of a sputtered aluminium roll bond plate covered with an anti-reflective coating, which is integrated in the triple glazing. The collector has an overall heat loss coefficient $U_{collector}$= 0.7 W/(m² K). The collector acts also as an additional insulation and can further reduce the heat flux from the interior to ambient if the collector plate is above the ambient temperature. The collector is filled with argon to reduce the heat losses from the collector plate to the environment. The collector can be integrated in the post and beam construction of the façade like a standard façade glass element.

The general configuration and components of the prototype are shown in figure 3. The prototype has been tested for a first assessment of its efficiency and the determination of its potential for improvement. Especially pressure drop and efficiency curve were determined.



1. first glass layer, 4 mm
2. space holder for the incorporation of the absorber
3. temperature-proof edge-bond
4. absorber with absorbing layer
5. second glass layer, 4 mm enamelled
6. temperature-proof edge-bond
7. space holder
8. third glass layer, 4mm
9. argon gas-filling
10. pressure compensation

Fig. 3. Configuration of the full-glass façade-collector developed by Energy Glas GmbH

The pressure drop of a single collector has a high influence on the piping concept for the whole façade. Before the installation, a collector prototype with an aperture area of 1.74 m² was investigated regarding its pressure loss in the laboratories of Kassel University.

Figure 4 represents the experimentally tested and theoretically calculated values for the pressure drop. Three flow rates have been measured, 68 l/h, 93 l/h and 106 l/h. The flow rate should be around 200 l/h for a collector field with six collectors connected in series.

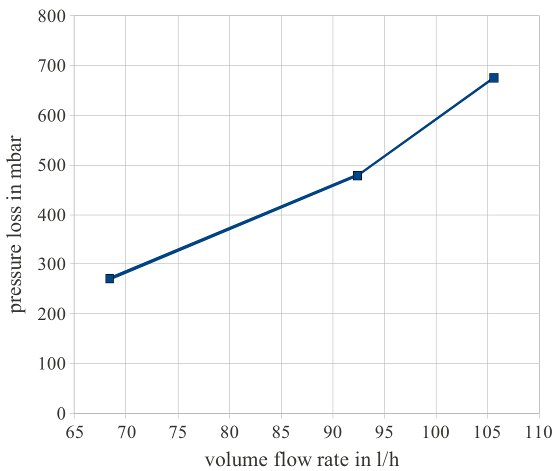


Fig. 4. Pressure losses in the absorber for three different flow rates

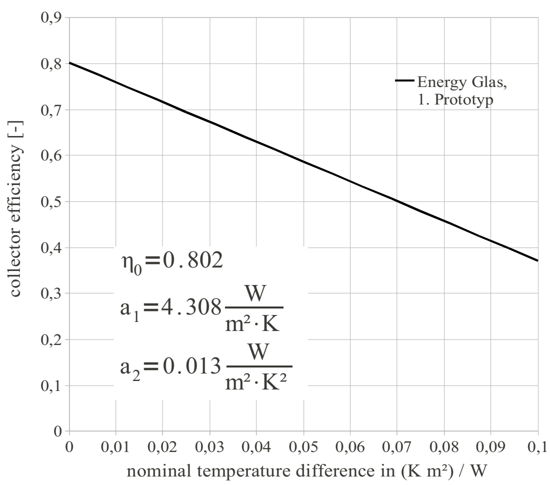


Fig. 5. Efficiency curve based on aperture area 1.74 m² at 800 W/m²

The pressure drop is very high compared to conventional flat plate collectors due to the tiny channels in the roll bond plate. Therefore each collector in the pilot plant was installed in parallel by a 'Tichelmann' hydraulic configuration so that energy efficient pumps could be used for the collector circuit. The roll bond plate has been redesigned and optimized for lower pressure losses as a consequence of these measurements so that the future product can also be installed with serial strings.

Furthermore, the thermal efficiency of the prototype has been examined. The efficiency curve and the corresponding parameters, which give an overview over the total performance of the product, are presented in figure 5. The optical efficiency of the prototype matches the state-of-art. The heat loss coefficient a_1 is higher than for standard collectors which usually reach a value of 3.5 W/(m² K) and has been reduced in the further product development by increased insulation and an improved flow configuration through the collector plate.

2.3. Multi-component storage

The ‘Energy Central’ includes the peripheral equipment required for the efficient function of the system. It consists of a strong insulated and (in the planning phase) free scalable thermal buffer storage as well as a flexible attachable periphery including controller for the connection of different heat sources and sinks.

The installed tank has a volume of about 5.000 litres with an insulation of 120 mm polyurethane hard foam. The tank can be integrated in every existing building as it consists of multiple components which are assembled on-site. Therefore it fits excellently for renovation purposes. The large volume allows the integration of powerful internal heating coils. The domestic hot water preparation is ensured by an internal coil made of stainless steel with a diameter of 40 mm and a length of 50 m. This heat exchanger reaches a discharging power of 210 kW at 45°C for a standby volume of 800 litres at 55°C and a cold water inlet temperature of 10°C. The auxiliary heating and room heating circuit are integrated with internal heat exchangers as well. The solar circuit heats the storage via an external heat exchanger and an integrated stratification pipe

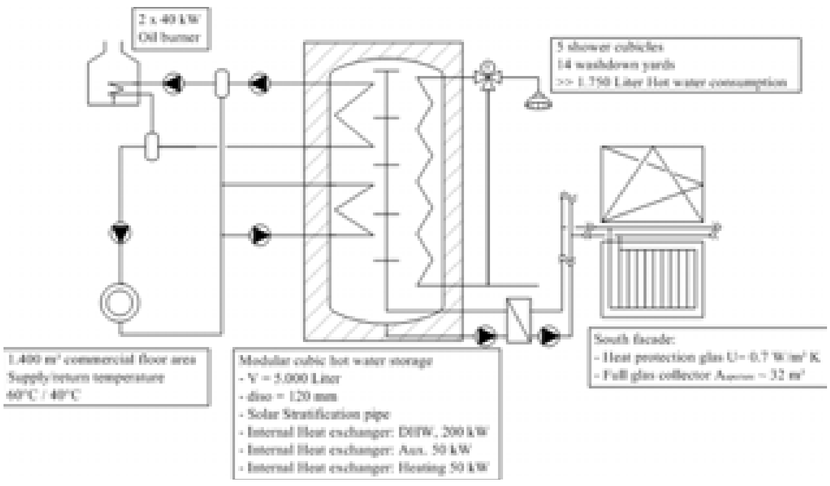


Fig. 6. Hydraulic scheme of the demonstration plant.

Fig. 7. Installation of the FLEXSAVE heat storage of FSAVE Solartechnik GmbH.

3. Demonstration plant

In February 2010, a first field test unit was realized and commissioned at the administration building of the partner company Heinrich LAMPARTER Stahlbau GmbH & Co. KG in Kaufungen, Germany. As consortium manager Heinrich LAMPARTER introduced its huge experience in steel and glass façades and project management in order to realize the holistic approach of the project. In combination with the need of renovation of the existing façade it was clear that all experiments on a pilot plant should be undertaken here.

Fig. 8. South façade of the head quarter of Heinrich LAMPARTER Stahlbau GmbH & Co. KG before and after the renovation

Figure 8 depicts the south façade before and after the installation of the solar thermal energy façade. The following measures for upgrading heat insulation were applied during the renovation phase:

1. Insulation of the roof by 160 mm expanded polystyrene foam with a thermal conductivity of λ=0.035 W/(m K)
2. Insulation of the whole façade by 100 mm mineral wool with a thermal conductivity of λ=0.035 W/(m K)
3. Exchange of windows with double glazing with a heat transfer coefficient U_g = 2.1 W/(m² K) into triple glazing with U_g = 0.7 W/m²K

Table 1 shows the calculated potential [3] of thermal energy savings by the above mentioned measures. The primary energy demand of the building can be reduced by 37% from 581 kWh/(m² a) to 367 kWh/(m² a).

Table 1. Specific energy consumption of Lamparter administration building according to ENEV calculations [3]

	Before the renovation	**After the renovation**	**Reduction in %**
Specific annual final energy demand [kWh/m² a]	481	293	39
Specific annual primary energy demand [kWh/m² a]	581	367	37
Specific annual heating demand [kWh/m² a]	293	172	41

3.1. Evaluation of measurements and simulation results

The whole installation is equipped with sensors for temperatures, flow rates, pressures and radiation to monitor the operation of the system and to calculate the heat fluxes in all circuits.

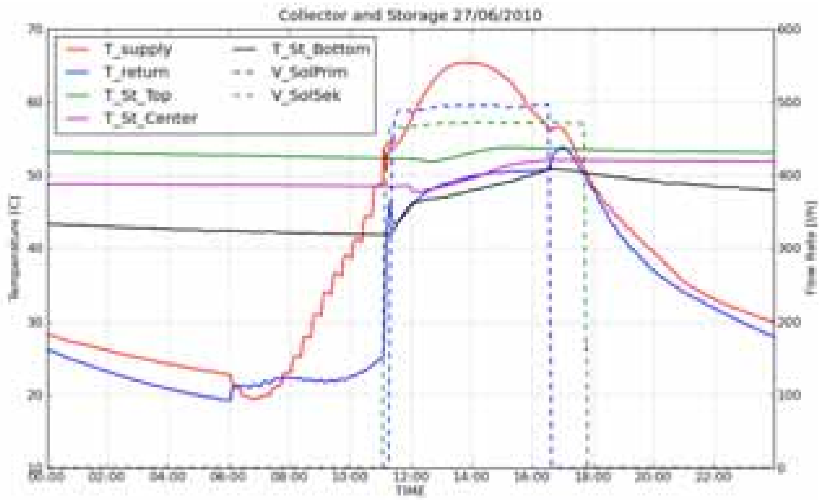


Fig. 9. Measurements of the solar circuit performance for June 27th 2010 at the pilot plant

Figure 9 shows on the left vertical axis the inlet and outlet temperatures of the collector, the temperatures in the storage at the bottom, centre and top. The right vertical axis represents the flow rates in the primary and secondary solar circuit. The storage temperatures are between 41 °C and 53 °C. The collector output temperature is measured in the collecting pipe and rises during the day from 20 °C to 65 °C. The echelon form of the collector output temperature during the heating phase occurs due to the control algorithm of the solar circuit. As the collector plate temperature can not be measured in the first collector prototype, the control operates the primary solar pump every 20 minutes for fifteen seconds and therefore transports the heat generated by the collectors to the temperature sensor. The primary collector circuit turns on permanently if the collector reaches the lower storage temperature plus the activation hysteresis. Also the secondary circuit is operated with respect to a minimum temperature difference between primary and secondary collector circuit.

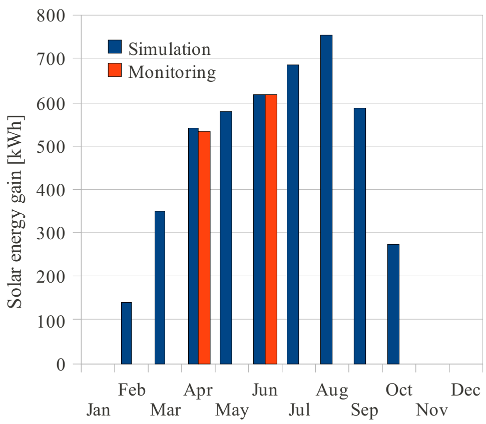


Fig. 10. Solar energy yield measured in April and June 2010 at the demonstration plant and as a result of the annual simulation.

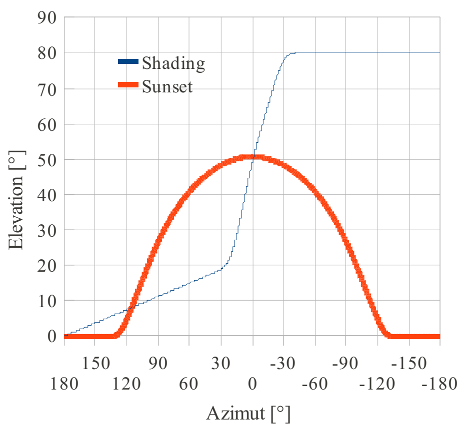


Fig. 11. The south façade of the Lamparter building is strongly shaded due to neighbouring buildings.

The storage is charged in the bottom region. The graph can be seen as an exemplary proof of the concept. Furthermore, a simulation model has been created in TRNSYS 17, which is parametrized with the specific properties of each installed component, the building and consumer profiles. The weather data are based on TRY 1996-2005 for Kassel, Germany. The purpose of the simulations is to give a forecast on the annual performance.

Figure 10 presents the annual simulation results for the solar energy yield to the storage for every month. The total yield predicted by the simulation amounts 4.500 kWh/a.

The specific yield referred to the aperture collector area amounts 140 kWh/(m² a). This very low specific yield is caused by significant shading due to neighbouring buildings as shown in figure 11. The solar yields reach 10.800 kWh/a or specifically 340 kWh/(m² a) if shading is eliminated in the simulations. The simulation results are approved by the first measured results of monitored data. The solar yields based on measurements coincide very good with the simulation results for April and June 2010.

4. Conclusions and future outlook

During the project time all set goals were reached. A pilot plant of a solar thermal energy façade was realized. It combines the aims to create an architecturally inspiring façade and a holistic approach – from the tank to the façade – and is ready for the market. The functionality could be approved by daily and monthly evaluation of the monitoring data and annual simulations. Single components could be improved as result of the above mentioned experiments. It was shown within the pilot plant that the system is excellently usable for renovation purposes. The solar energy façade can now be delivered by the consortium manager in cooperation with the other project partners and thus the holistic approach can be realized.

5. Acknowledgements

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