Development of integrated passive and active roof modules

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Abstract

A novel, integral roof in a modular design where the single roof modules fulfil different tasks and at the same time serve as outside insulation is developed by the Austrian company "Metallwerk Friedrich Deutsch GmbH". A solar thermal module, a photovoltaic module, a rooflight module and a blank module (insulation only) are developed and will soon be available on the market. For the development task, an interdisciplinary team is appointed to handle the complex thermal, structural-physical and stress design related issues. In this paper the development of the solar thermal module with special regard to the thermal aspects is discussed.

1. Introduction

The Austrian company "Metallwerk Friedrich Deutsch GmbH" had the idea to develop a novel, integral roof in a modular design where the single roof modules are employed in different applications and at the same time serve as outside insulation. The different applications are: active use of solar energy by means of solar thermal and photovoltaic modules, passive use of solar energy by means of a rooflight module and a blank module (insulation only) whereas for all modules the insulation is to meet the passive house standard.

Fig. 1 shows an example how the roof can be composed out of different detiga^{TM} modules.

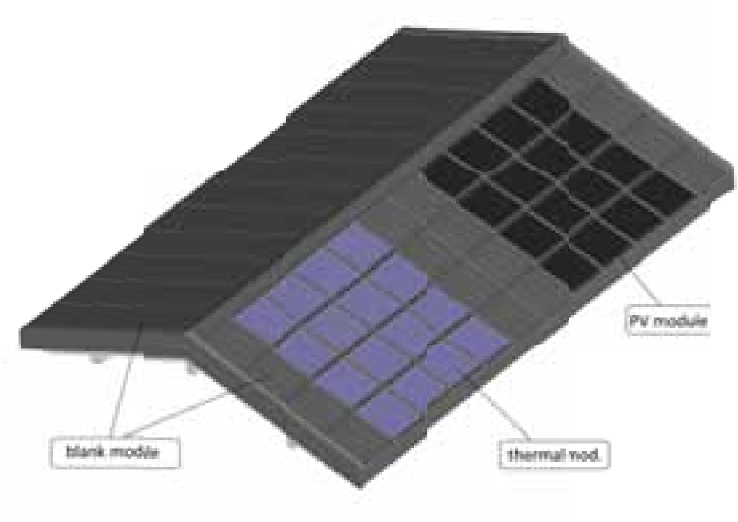

Fig. 1: Design of the roof with solar thermal, photovoltaic and blank detiga^{TM} module

The final objective of the project is to develop a package of handy modules that can quickly be installed on roofs with any slope and that allows for competitive active and passive use of solar energy. For the development task an interdisciplinary team is appointed to handle the complex thermal, structural-physical and stress design related issues. The results from the different research fields are merged and incorporated in the newly developed roof module system.

In this paper the thermal aspects that came up in the development of the solar thermal module are discussed.

2. Development of an active solar thermal module

One main requirement on the modules was to be handy (approx. 70 x 70 cm) and easy to install on roofs of any slope. The developed design prototype was evaluated in terms of thermal stress by means of simulations using different theoretical approaches.

For the development of the solar thermal module the following requirements have been identified:

- a collector characteristics that allows for efficient operation as a solar thermal combisystem (domestic hot water production and space heating)
- costs that are considerably below the costs of a common flat plate collector (achieved by using thermal stress optimized materials)
- maximum safety concerning stagnation by the use of drain back-capable absorbers (meander geometry)
- minimum assembly time by the use of hydraulic quick couplings where no tools are needed (plug & flow assembly)

2.1. Collector characteristic

When a new collector is developed, the collector characteristic is of interest from the very beginning. This is a challenge because accurate prognoses are claimed before the development has reached a stage where fabrication of a prototype for experimental tests that would give reliable results is reasonable.

At this stage it is more efficient to evaluate the collector in a theoretical model where modifications can easily be integrated. The aim of the analytical approach is to compute and demonstrate the efficiency and the useful energy gain of the collector. With the results from the simulation, statements about effects of changing the collector design on the performance of the collector can be made.

The design prototype already had a quite complex geometry, which caused problems with the simulation models in Kolektor 2.2 [1] and Solar08 [2]: they did not evaluate the heat losses of the collector module correctly. For this reason, those two simulation models were employed only for the evaluation of the collector characteristic, whereas COMSOL Multiphysics [3] was employed for detailed thermic and hydraulic analysis using the finite elements method.

The simulation programs Kolektor 2.2 and Solar08 both use the same theoretical model [4] whereas they differ in the focus of the analysis: Kolektor 2.2 concentrates on different theoretical approaches that are available for convection and radiation at the glazing and in the air gap between the glazing and the absorber. In contrast, in Solar08 the main focus is on the detailed simulation of the transparent glazing and the heat losses through the side and the rear walls.

To validate the models, the simulation results were compared to experimental results according to ÖNORM EN 12975 [5]. Six different collectors that represent the common spectrum of flat plate collectors and that are documented very well were chosen and simulated with Kolektor 2.2 as well as with Solar08. Fig. 2 shows the results from both simulation programs and the experiments for two of the six collector types.

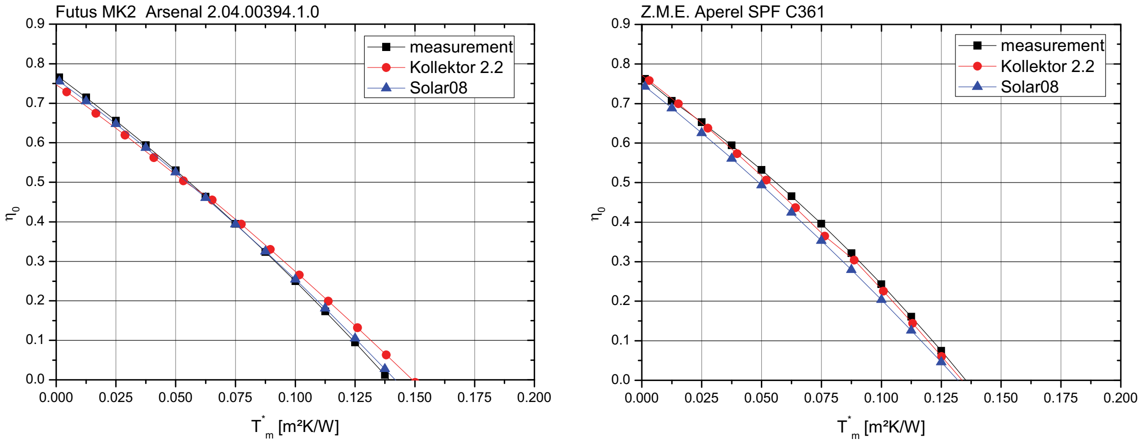

Fig. 2: Comparison of collector characteristic from simulations and from measurements. Left box: Futus MK2 collector from Futus Energietechnik [6]. Right box: Aperel collector from Z.M.E. [7]

As the results from the simulations and the experiments match very well, it is assumed for further investigations that the collector efficiency is evaluated properly both in Kolektor 2.2 and Solar08.

However, the simulation of the newly developed collector holds another challenge because it is different from common flat plate collectors: the vat element of the collector (vat made of aluminium) passes the thermal insulation. For this reason the whole solar thermal module was simulated in COMSOL in order to investigate the thermal losses across the glazing, the side walls and the rear wall properly. The results from COMSOL for the thermal losses were then used as input for the simulation in Kolektor 2.2 and Solar08, whereby the collector characteristic was evaluated.

In order to rank the newly developed collector within the spectrum of common flat plate collectors with respect to its efficiency, three typical flat plate collectors ranging from "low cost" to "good" to "very good" from the SPF - collector database [7] were chosen for comparison (SPF low cost, SPF good and SPF C442).

The first draft of the collector design was an uncovered collector that was intended to be used in combination with a heat pump. The evaluation was done for two variants: detiga^{TM}_00a with non-selective coating of the absorber and detiga^{TM}_00b with selective coating (see Fig. 3). The market for collectors that are only intended to be installed in combination with a heat pump has not been established yet, for this reason a single glazing has been attached to the collector. Starting from that point, different measures were taken to further improve the collector characteristic (see Fig. 3, detiga^{TM}_01 to detiga^{TM}_03).

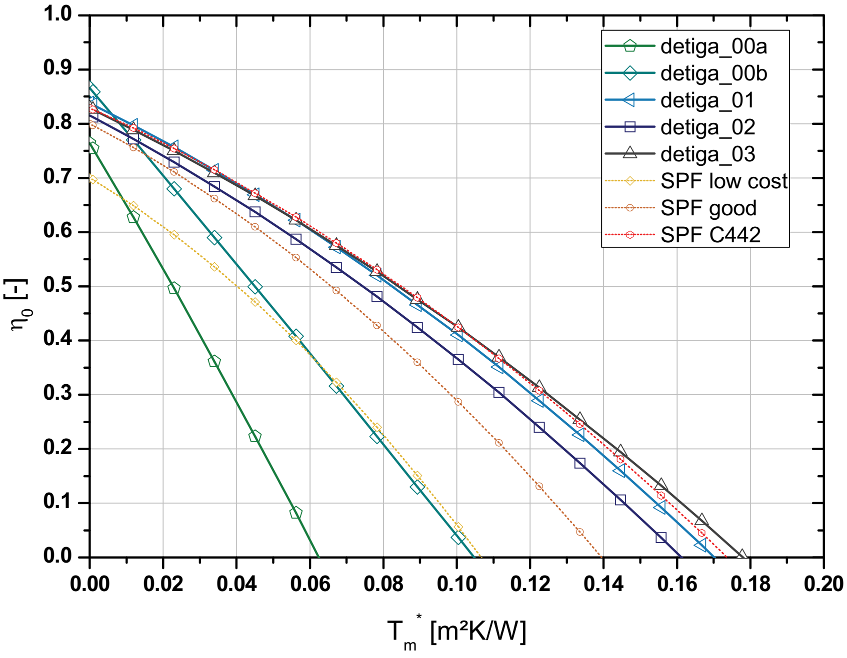

Fig. 3: Theoretically estimated collector characteristic at different stages in the development of the detiga^{TM} collector in comparison to the flat plate collectors from the SPF - collector database [7]

The following parameters have been changed in the development process:

- thickness and material of the absorber sheet
- design of the coupling between absorber pipe and absorber sheet
- distance between the absorber pipes
- distance between absorber sheet and glazing (air gap)
- insulation at the rear side of the absorber
- thickness and material of the glazing

With these parameters optimized (detiga^{TM}_03), a theoretical collector characteristic that keeps up with the SPF C442 [7] can be reached. Table 1 shows the coefficients of the collector characteristic, the efficiency at 60 °C collector mean temperature and the expected temperature of stagnation at 1000 W/m² global irradiation and 30 °C ambient temperature for detiga^{TM}_03 calculated in Solar08 and Kolektor 2.2.

Table 1: Coefficients of the collector characteristic, efficiency at T_M =60 °C collector mean temperature and expected temperature of stagnation at 1000 W/m^2 global irradiation and 30 °C ambient temperature for detiga^{TM}_03 calculated in Solar08 and Kolektor 2.2

	η_0	a_0	a_1	$\eta(T_M=60)$	T_{STG}
Solar_08	0.829	3.224	0.0101	64.7%	208
Kolektor_2.2	0.828	3.890	0.0057	62.2%	206

2.2. Thermal stress of materials

When being in permanent operation, not only the characteristic of the collector is of interest but also the temperatures that occur in the collector. The maximum as well as the minimum and the permanent temperatures provoke thermal stress of the materials and make great demands on them. In order to evaluate the thermal stress at different positions in the collector, it is necessary to simulate the whole collector in a FEM software, e.g. COMSOL.

Variants that represent different realistic operational states such as an extreme winter day, summer days with different solar irradiation and flow (from zero flow up to 60 l/m^{2}h) have been simulated in COMSOL. Fig. 4 shows the temperature distribution at the position where the solar thermal modules overlap each other on a typical summer day (left box) and on a typical winter day (right box), both with a flow temperature of 80 °C.

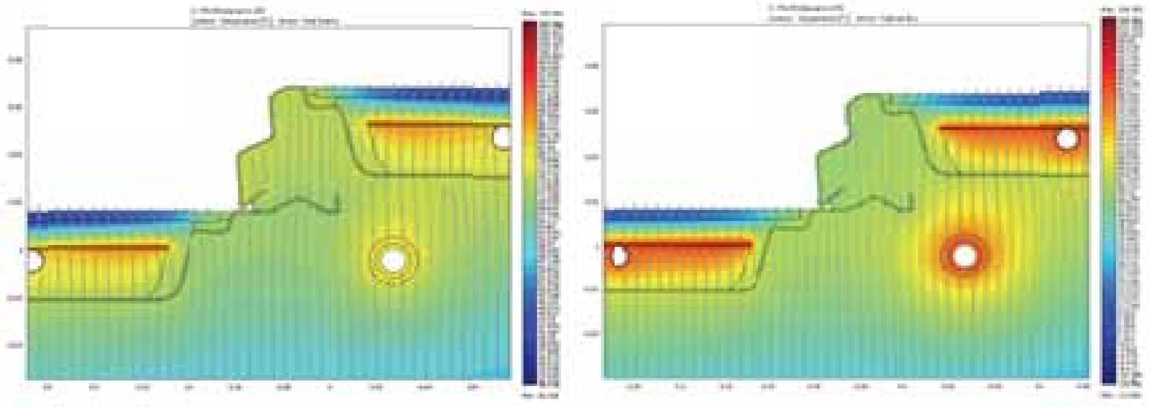

Fig. 4: Temperature distribution at the position where the solar thermal modules overlap each other on a summer day (left box) and on a winter day (right box) both with a flow temperature of 80 °C

For the evaluation of the maximum thermal stress, the stagnation case according to ÖNORM 12975-2 [5] was assumed and simulated in a 45° sloped collector. The influence of the collector slope on the expected maximum temperature in the collector is discussed in chapter 2.3.

The temperature distribution in the collector and the flow velocity in the air gap between the absorber and the glazing are depicted in Fig. 5.

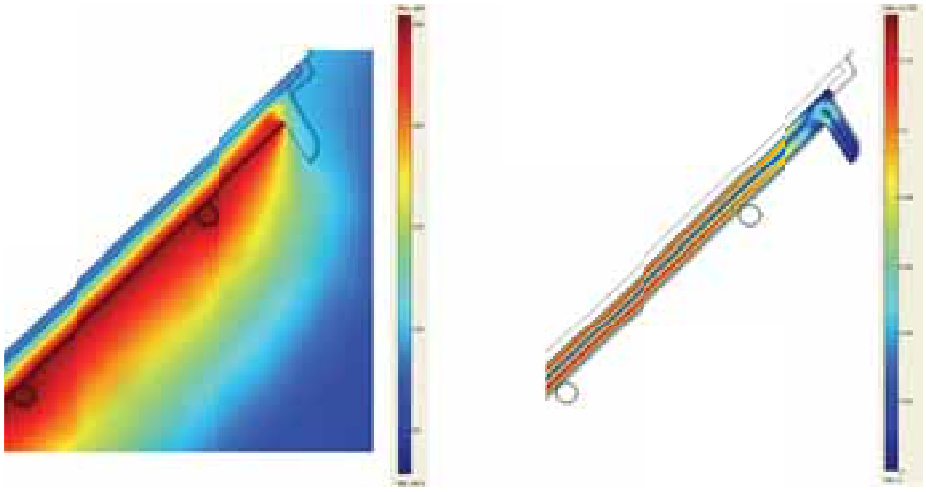

Fig. 5: Temperature distribution within the thermal collector (left side) and velocity field within the air gap between the absorber and the glazing (right side) at 30°C ambient temperature and 1000 W/m² global irradiation

2.3. Influence of collector slope on the collector efficiency

Typical roof slopes range from 12° to 45° which is expected to influence the temperature distribution in the collector. A high collector efficiency is reached when the temperature field in the collector is even at a high level.

To evaluate this influence, the detiga^{TM}_02 collector was simulated in COMSOL with different values for the collector slope (45, 32, 22 and 12°) in stagnation case. The physical phenomenon that is of the main interest are Bénard-cells that arise between two plates whereof one is heated and the other one is cooled. Reaching a critical temperature difference, these geometrically structured convective cells arise. Fig. 6 shows the temperature distribution in the middle of the absorber with 10 mm air gap at the different collector slopes and the velocity field for the 32° sloped collector.

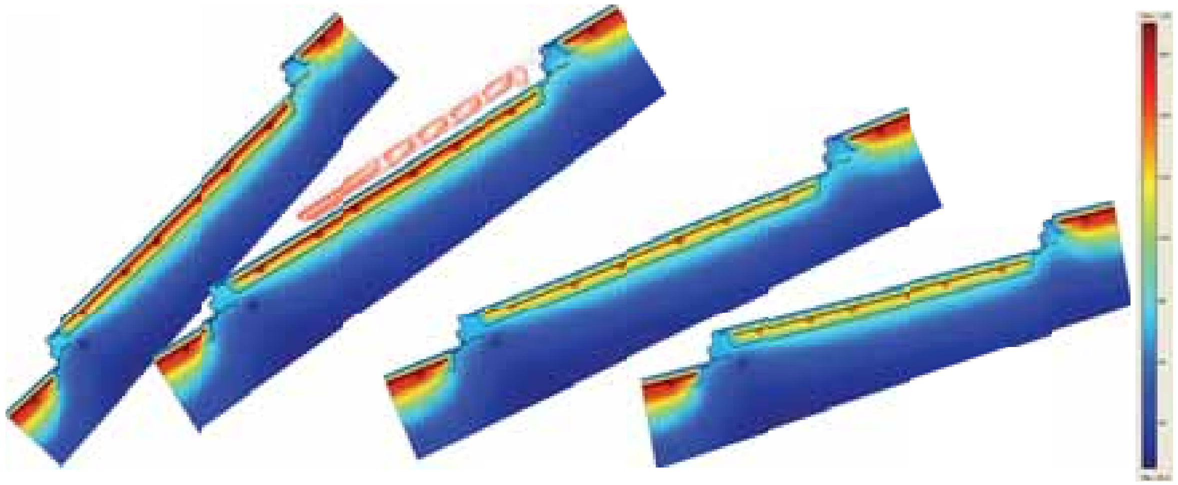

Fig. 6: Temperature distribution at different collector slopes (45, 32, 22 and 12°) and velocity field at 32° collector slope with 10 mm air gap

In the 45° sloped collector, no Bénard cells arise and the temperature field is even. In the 32° sloped collector, Bénard cells begin to arise in the upper part of the air gap. Decreasing the collector slope further, the Bénard cells spread downwards and fill the whole air gap.

Fig. 7 shows the temperature line across the absorber for the same variants as in Fig. 6. In the variants with a collector slope of 12° and 22°, the Bénard cells are distributed homogenously across the absorber. These cells effect stronger convection in the air gap, hence higher heat losses and accordingly a lower and almost even temperature across the absorber in contrast to stronger sloped collectors. If the Bénard cells arise only in the upper part of the air gap (at a slope of 32°), the temperature of the absorber decreases only in that area and the lower part of the absorber reaches significantly higher temperatures than in a less sloped collector. At high collector slopes, no Bénard cells arise and the temperature line across the absorber is almost linear again, but at a higher level and rising stronger than for the less sloped collectors.

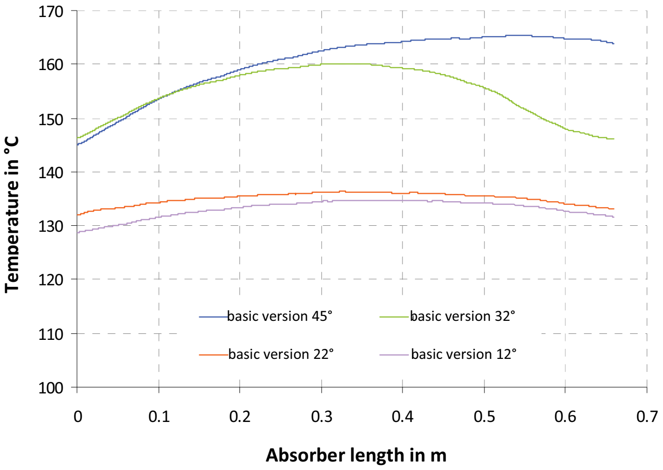

Fig. 7: Temperature line across the absorber at 10 mm air gap and different collector slopes

It is known from other investigations that not only the collector slope but also the size of the air gap between the absorber and the glazing has a strong influence on the collector efficiency. This issue is discussed in more detail in [8].

3. Conclusions and outlook

For a modular roofing system, a solar thermal module with a flat plate collector has been developed and evaluated in simulations. As the design of the module differs from common collector designs, the simple theoretical models were not suitable to simulate the heat losses properly, for this reason a FEM-model (built in COMSOL) was employed for those investigations. There the intrinsic physical processes taking place within the collector (conduction, radiation and convection) are simulated and the effect of changes in the design of the solar thermal module (both geometric and material changes) on the efficiency of the collector (collector characteristic and stagnation temperature) can be evaluated in an efficient and economical way.

The formation of Bénard cells, that lead to a significant decrease of the temperatures at the absorber are dependent on both the collector slope and the air gap between the absorber and the glazing (for the latter, see [8]).

At present, the "second generation" of the collector, the detiga^{TM}_02, is being tested on the outdoor test rig at Metallwerk Friedrich Deutsch GmbH. The results from the measurements will be included in the validation of the simulation models.

In parallel, detail problems, e.g. thermal stability of components or outgassing of materials are worked on and suitable system hydraulics for the solar thermal modules will be designed.

Acknowledgement

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