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Performance and reliability of insulated glass collector prototypes

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Abstract

Insulated glass collectors represent a novel design intended for improved building integration, combining a multiple window glazing with a flat plate collector. Gas-filled gaps and low-emittance glass coatings can provide for a high performance, comparable to that of commercially available flat plate products by reducing the overall thickness from 90-100 mm to 50 mm. The paper presents the results of our investigations on optimized triple-glazed, argon-filled prototypes. Aim of the work is to compare different absorber technologies and integration solutions and to identify the most suitable design with regards to aesthetical appearance and long-term reliability. Efficiency measurements according to EN ISO 9806 confirm the findings of previous investigations: zero-loss efficiency η_0 between 0.74 and 0.79 as well as an effective heat loss coefficient a_{40} between 4.2 and 4.5 W/m²K are reported, depending on the specific design considered. Indoor and outdoor reliability tests show promising results: no significant decrease of gas concentration has been detected in most cases and no degradation of the collector components, even after long-term exposure. Due to the gas-tightness of the unit, outgassing has been identified as a critical aspect to be taken into special consideration in the collector design and in the choice of components and materials.

keywords: flat plate collector, insulated glass, building integration.

1. Introduction

Insulated glass collectors represent a novel design combining a multiple window glazing with a solar thermal flat plate collector. A flexible manufacturing, an easy integration in common window frames or façade profiles as well as a superior aesthetical quality make them best suitable for building integration. As a result, a higher architectural acceptance and a reduction of installation costs are expected. Both aspects can significantly contribute to a successful deployment of solar thermal systems.

Previous theoretical and experimental studies have already shown the potential of this new collector (Lamparter, 2010; Schleffer, 2010; Giovannetti et al., 2014): by the use of gas-filled gaps and low-emittance glass coatings, performance values comparable to those of commercially available flat plate collectors can be achieved with a slim design (down to 50 mm).

This paper presents the results of our investigations on improved argon-filled, triple-glazed collector prototypes featuring different absorber technologies and integration solutions. The design optimization aims on the one hand at simplifying the construction and adapting it to the manufacturing steps of the insulated glass production, on the other hand at ensuring the long-term reliability of these collectors, which hasn't been demonstrated so far.

2. Design of the collector prototypes

The choice of the right absorber design and the right integration into the glazing unit represent the most challenging tasks in the development of this new collector. To achieve a superior aesthetical quality, comparable to that of other glazed components of the building envelope, an unusually flat plate has to be implemented and typical corrugated patterns of metallic absorbers should be avoided. Preliminary tests on

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laser-welded sheet-and-tube absorbers showed that this most common design cannot fulfill the targeted requirements, even by using much thicker plates (up to 1 mm aluminum instead of the typical 0.4/0.5 mm). For this reason we investigated alternative solutions and identified three promising products (s. Figure 1). Two of them are based on the use of additional metallic omega profiles placed on the rear side of the absorber to fix the tubing to the absorber plate and to provide for the necessary thermal contact, whereas different processing technologies are implemented. In one case the profiles are glued to the plate with a very thin and temperature-resistant acrylic adhesive tape. This design is known since long time, was introduced to the market by the German company Schüco and is currently commercialized by the German company SolMetall. To analyze the influence of the design parameters on aesthetics, performance and reliability (for example width and thickness of the omega profile, type and application of the adhesive tape) in-house prototypes were developed and manufactured in cooperation with our project partners.

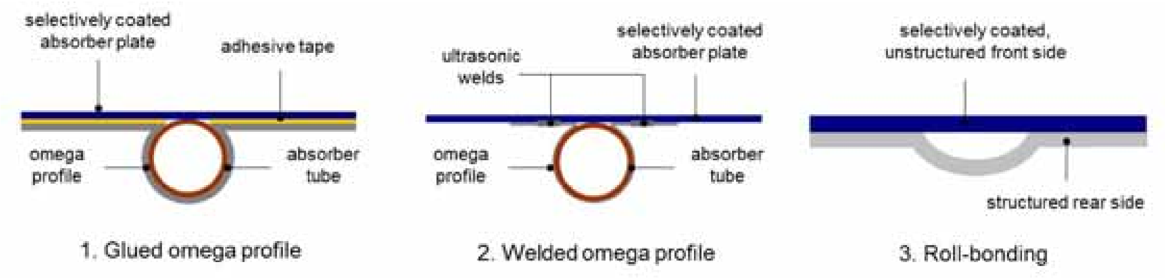

Fig. 1: Sketches of commercially available absorber designs with superior aesthetical quality, identified as best suitable for the use in insulated glass collectors

In the second case the omega profile is fixed to the rear side of the absorber plate by ultrasonic welding. Geometry and welding process can also in this case strongly affect the absorber behavior. For our investigations, the absorber prototypes were manufactured and supplied by the Macedonian company Camel Solar.

The use of additional omega profiles provides for a superior aesthetic appearance by avoiding the damage of the absorber surface during the processing and by reducing the thermo-mechanical stress at the boundary between plate and tubing and the correspondent absorber deformation, especially if different materials are used (for example aluminum and copper).

The last suitable absorber manufacturing technology identified is roll-bonding. Latest developments enable the production of asymmetric assemblies featuring a rear side with visible hydraulic structures and a very flat front side, by using two aluminum alloys with different mechanical properties. Highly performing selective coatings can now be applied as well. The successful developments were carried out by the Italian company CGA and by the Finnish collector manufacturer Savosolar. Absorber prototypes couldn't be supplied within the runtime of the project, so that our investigations focused on the first two absorber designs.

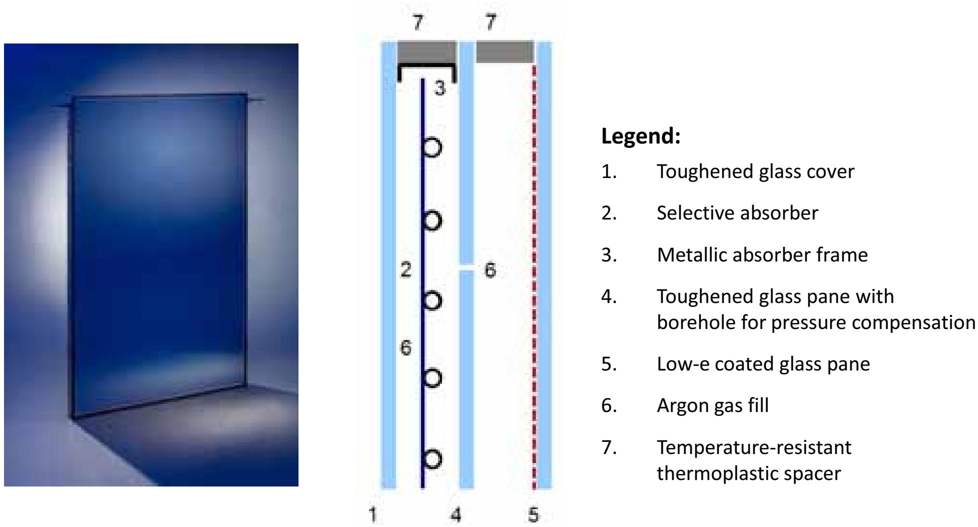

Fig. 2: Sketch (right) and prototype (left) of an insulated glass flat plate collector

To insert the solar absorber into the glazed unit we tested different solutions as well. The main development goal was to realize a simple assembly, which can be manufactured by using the production equipment of insulated glass with thermoplastic spacers and can withstand the high thermo-mechanical stress occurring during operation and in case of stagnation. To this intent the absorber is framed by a metallic profile, which ensures the mechanical stability to the whole construction, thus strongly simplifying the handling during the manufacturing steps, and avoids the direct contact of the hot plate with the temperature sensitive edge bond, mainly responsible for the durability of the glass unit. For the sealants high-performance products developed by the German company Kömmerling Chemische Fabrik and already successfully tested for solar thermal applications were used (Föste et al., 2014).

To reduce the absorber deformation and the mechanical stress at the edge bond, which can also impair the gas-tightness of the glazing, additional fixings placed on the rear side of the absorber plate as well as special components compensating the thermal elongation of the tubing were used in the first collectors. In the second, optimized generation of prototypes these complex and cost intensive devices were removed.

On the basis of the presented design approach several collector prototypes were produced (s. Figure 2). The procedure consists of the following main steps, which can be repeated in the case of triple or quadruple glazing: positioning of the first pane, application of the primary sealant (modified butyl), positioning of the second pane, filling of the gap with argon gas and pressing of the two panes. In our case one of the panes is replaced by the framed absorber. At last, the secondary sealant (silicon), responsible for the mechanical stability of the glazed unit, is applied. The results prove that the developed collector design is compatible with this procedure and that optimized prototypes with a simplified assembly can be manufactured with a high automation grade.

3. Collector measurements

3.1. Performance

We carried out efficiency measurements on the different collectors according to EN ISO 9806, by means of indoor tests with our solar simulator, which ensures a high reproducibility and an uncertainly of less than 0.01 over the relevant temperature range. Despite of the different design, all prototypes exhibit identical optical properties of glass cover ($\tau = 0.90 \pm 0.01$), absorber ($\alpha = 0.94 \pm 0.01$, $\varepsilon = 0.05 \pm 0.02$) and low-e glass ($\varepsilon = 0.03 \pm 0.02$). The collectors were measured both at 45° and 90° inclination to analyze the impact of the convective heat transfer mechanisms on the overall performance. The tests confirm the results of our previous investigations (Giovannetti et al., 2014) and can be summed up as follows:

- As reported is Figure 3, the performance of the insulated glass collectors is comparable to that of a commercially available flat plate collector, featuring a low-iron glass cover ($\tau = 0.90 \pm 0.01$), a selective absorber, consisting of a 0.4 mm thick aluminum plate and copper pipes ($\alpha = 0.94 \pm 0.01$, $\varepsilon = 0.05 \pm 0.02$), and 50 mm rear side insulation.

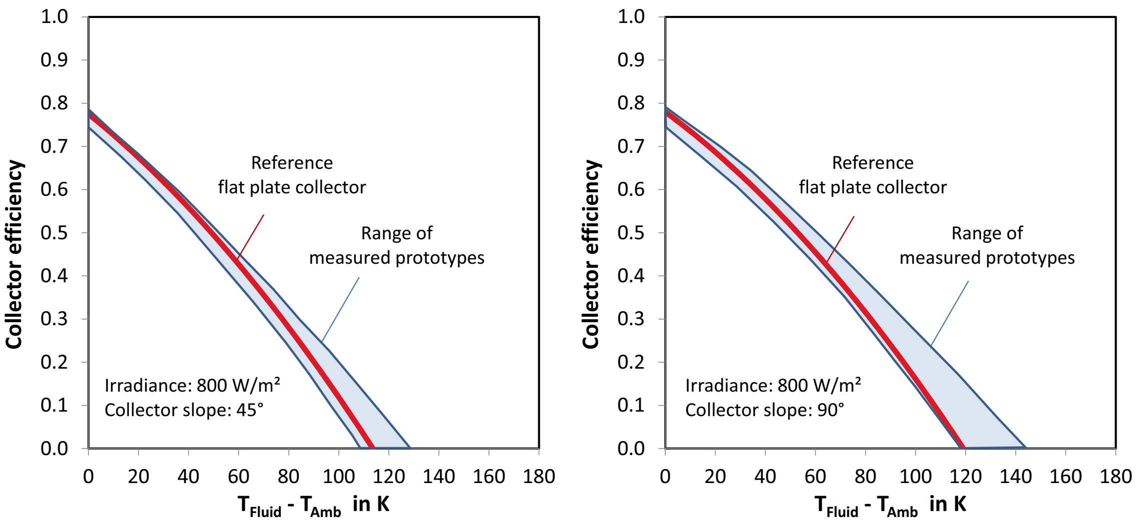

Fig. 3: Measured efficiency of argon-filled, insulated glass collector prototypes compared to that of a standard flat plate collector at 45° (left) and 90° (right) slope

At 90° inclination the glass collectors perform even better due to the advantageous reduction of the convective heat losses.

- The conversion factor η_0 ranges between 0.74 and 0.79, slightly below that of the reference collector. This variation is mainly due to the selected absorber design, implementing additional omega profiles. The geometry of the profiles as well as the welding or gluing process used have a strong influence on the heat transfer between the absorber plate and the fluid, which in turn affects the zero-loss efficiency of the collector (Rockendorf et al., 1995), as shown in Figure 4 for the correspondent configuration.

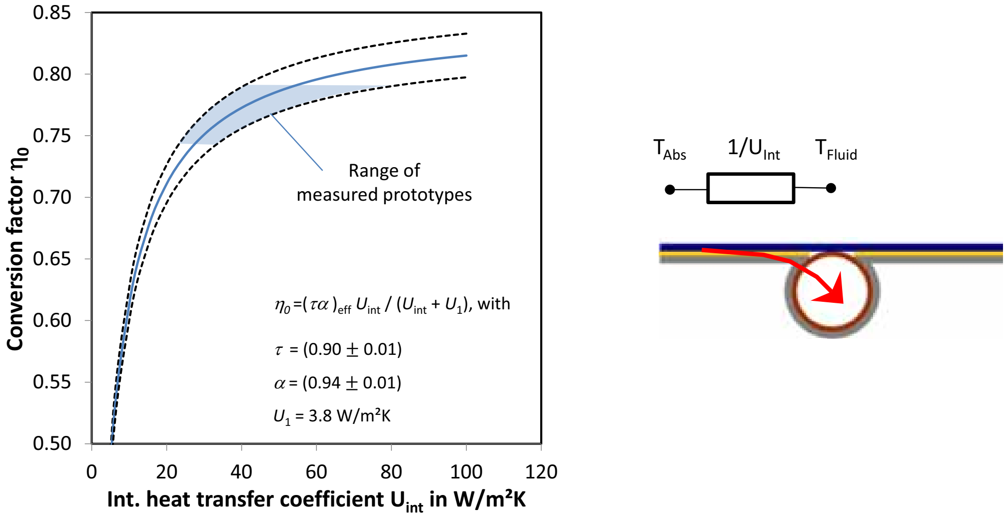

Fig. 4: Calculated influence of the absorber internal heat transfer coefficient U_{int} on the conversion factor of a flat plate collector, based on the optical and thermal properties of the investigated prototypes

- The effective heat loss coefficient a_{40}, referred to a temperature difference (T_{Fluid} - $T_{Ambient}$) of 40 K, ranges between 4.2 and 4.5 W/m²K. The variation is in this case supposed to depend on the different emittance of the rear surface of the absorber plates, more than on the optical properties of the components or on the geometry of the collectors. Contrary to what assumed in our first investigations, calculation results attest an increase up to 0.5 W/m²K with very high emittance values. The calculation has been carried out with a model developed at ISFH and already described by Giovannetti et al. (2014). To suppress any possible negative influence of the absorber plate on the heat losses, a low-e coated middle glass pane can be used, as represented in Figure 5.

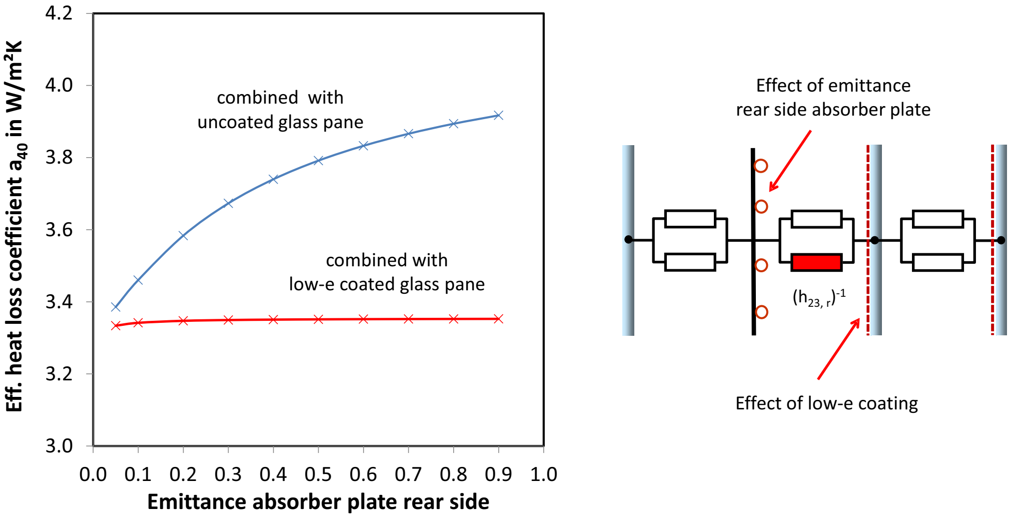

Fig. 5: Calculated dependency of the effective heat loss coefficient a_{40} of an insulated glass collector on the emittance of the rear side of the absorber plate by using an uncoated and a low-e coated middle glass pane. The calculation has been carried out with a model developed at ISFH and refers to the undisturbed central area of the collector. Any two- or three-dimensional effect as well as any thermal bridge are neglected.

3.2. Reliability

We investigated the collector reliability by means of both indoor and outdoor tests. Our main goal was to prove the durability of the glazed unit under severe exposure conditions and analyze the thermal and thermo-mechanical behavior of the collector. As assessment criteria, a visual inspection of the assemblies, an efficiency measurement and a measurement of the gas-tightness of the prototypes before and after the exposure were carried out.

The short indoor tests consist of cyclic temperature shocks (3 to 5 cycles) similar to EN ISO 9806 and were carried out in our solar simulator on most of the manufactured prototypes to get a first impression of the assembly stability in dependency of the different design solutions. During the tests, the unfilled collector is exposed to high temperatures over three hours under stagnation conditions (irradiance G about 1000 W/m², ambient air temperature T_{Air} about 30°C, no wind) and subsequently fast cooled down and flowed through over one hour with cold water at a constant temperature of about 20 °C.

During the outdoor tests three prototypes from the first manufacturing campaign have been investigated to analyze their long-term behavior. Two of them were installed on our test roof (south orientation, 38° slope) and the last one in our test façade (south orientation, 90° slope). This collector is inserted in a vinyl (PVC) window frame and fully integrated in the building, as it should be in a real installation.

All collectors are unfilled and not connected to the solar loop to maximize the stress, and equipped with resistor sensors PT-100 in order to get reliable information about the temperature distribution under real weather conditions, especially at critical positions of the assembly (edge bond, PVC-frame). Weather data (ambient temperature, wind speed and direction, hemispherical and diffuse irradiance) are recorded as well.

The test on the roof has been running since August 2013, the test in the façade since November 2013. The present work reports the results of the first 12 and 9 months exposure respectively.

Our reliability tests show in general promising results with regards to the durability of the insulated glass collectors. We have measured no change of Argon concentration in most of the prototypes investigated during the shock tests, independently of the design solution chosen (absorber and fixings). Two of the three collectors tested outdoor can provide for gas-tightness even after the long exposure time (Prototype 2 and Prototype 3 in Figure 6). Efficiency measurements on one of the prototype (Prototype 2) show identical heat loss coefficients before and after one year exposure.

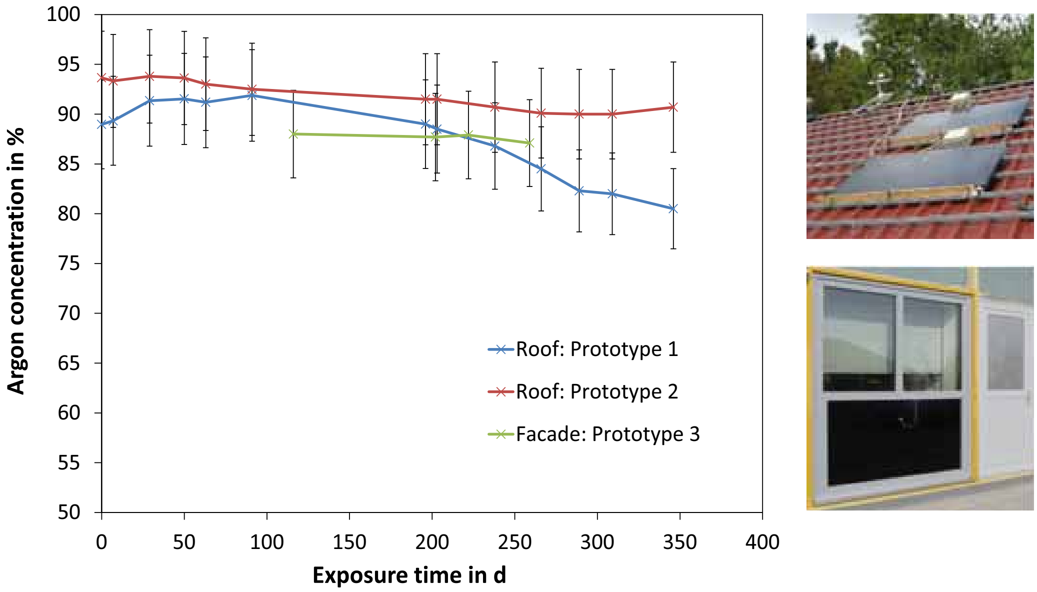

Fig. 6: Argon concentration in the front gap of the collectors in the course of the outdoor exposure tests (left) and pictures of the exposed collectors (right). The measurements have been carried out with the portable gas analyser Gasglass Handheld from the company Sparklike.

The investigations attest on the other hand a systematic reduction of the conversion factor after the extended shock tests (0.01 up to 0.03), due to a suboptimal design of the customized absorbers, which still has to be improved in order to fulfill both aesthetical and performance requirements.

The design temperatures at the critical positions in the collector have not or have only slightly been exceeded during the outdoor tests (s. Figure 7 and Figure 8). At the edge bond (long-term durability proven up to

140°C) a maximum temperature of 110°C was reported, at the PVC-frame (long-term durability of the material: 80°C) of 84°C. No relevant sign of degradation of the collector components was detected.

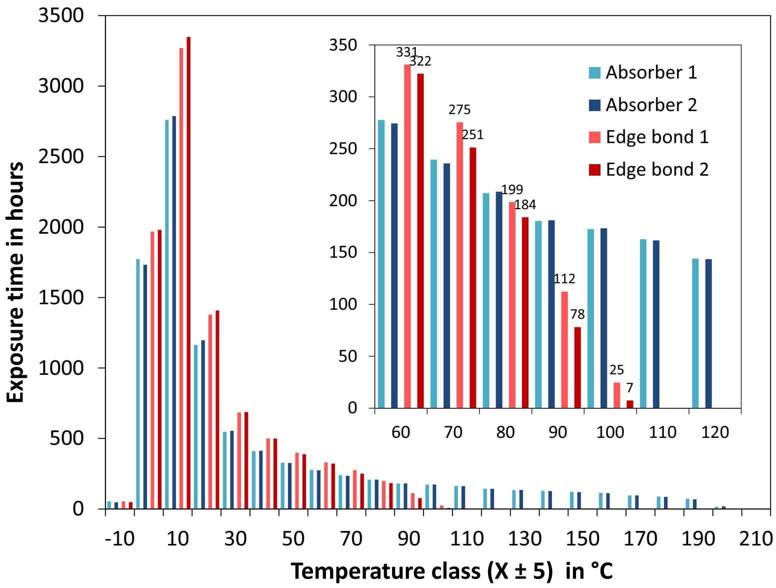

Fig. 7: Frequency distribution of the temperatures measured at the critical positions during the outdoor test on the roof: overview and detail of the relevant temperature range

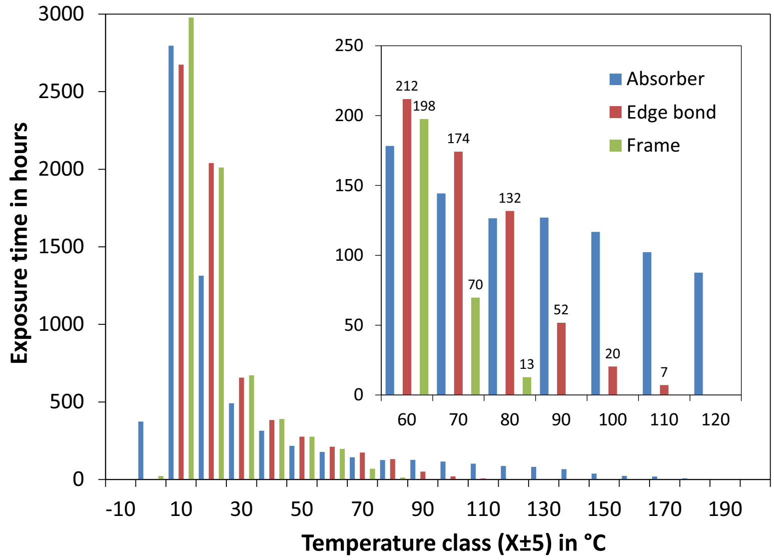

Fig. 8: Frequency distribution of the temperatures measured at the critical positions during the outdoor test in the façade: overview and detail of the relevant temperature range

Outgassing was observed in all investigated prototypes and has to be regarded as the most critical aspect in the development of this new collector design, due to the tightness of the glass unit. To solve the problem the use of any temperature sensitive material has to be avoided.

4. Conclusion

Our investigations on insulated glass collector prototypes prove that this new collector concept, combining an architectural glazing with a flat plate collector, exhibits a high potential for building integration.

The collector can be manufactured by using the standard equipment and production procedure of the insulated glass industry, thus promising a very flexible design which can be more easily adapted to different installation conditions. A superior aesthetical appearance, compared to most of the existing commercial products, can be achieved by using well-known absorber manufacturing technologies.

Efficiency measurements confirm our previous experiences, reporting performance values comparable or even better than those of commercially available flat plate collectors in spite of their slim design. Improvements still have to be undertaken to get the best compromise between aesthetics and performance.

By using a suitable design, featuring a framed solar absorber and high-performance sealants for the edge bond, the durability of the glazed unit can be ensured. Most of the collectors tested provide for the required gas-tightness, independently on the specific design. First short tests on optimized assemblies, eliminating complex absorber fixings and simplifying the manufacturing, show promising results as well. Avoiding outgassing still represents the most challenging task in the development of this new collector concept and can only be achieved through the choice of the right components and materials.

Future activities should address the long-term reliability of the new optimized design as well as the integration into the building envelope. For this purpose a demonstration project is planned.

5. Acknowledgements

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