SOLAR THERMAL COLLECTORS, STATE OF THE ART AND FURTHER DEVELOPMENT

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Abstract - The market for solar thermal collectors in central Europe is well established. New materials and designs which have led to substantial improvements in collector performance and quality since 1980 are discussed. Future collector designs are presented and compared against historical performance improvement trends. The suitability of flat plate and evacuated tube collectors for two standard applications is demonstrated.

1. INTRODUCTION

In central Europe, there exists a well-established market for solar thermal collectors. In 2001 over a million square meters of thermal collectors were sold. The main application is for domestic use such as hot water heating; however combined systems for hot water and space heating have a market share of about 25 percent.

There is still a large number of solar collector manufacturers in central Europe. More than 150 companies are attempting to successfully penetrate the market with their products. About 80 percent of the market is dominated by flat plate collectors. The remaining 20 percent are evacuated tubular collectors with a variety of designs such as heat pipe or direct flow, dewar-type tubes or “metal to glass seal” tubes.

The technical data as well as the design and construction of these products differ significantly. The relevant criteria in choosing a certain collector may be very different. In principle, they may be divided into technical (including optical design) and commercial aspects. A builder-owner may consider the following criteria to be of primary importance: thermal performance, quality, price, optical appearance and architectural integration.

To evaluate suitable products, a database including as many of the relevant criteria as possible is necessary. SPF (Institut für Solartechnik) publishes these data on a CD-ROM, including the software to select particular products /1/.

The technical data can be derived through measurements and testing of the collector products. Thermal performance and quality may be identified on the basis of international standards (EN and ISO). It is much more difficult to objectively judge the visual design of a collector or its architectural integration in a particular building. Both aspects are subject to individual taste.

During the last 20 years, the thermal performance and, just as importantly, the quality of the collectors have greatly improved. On the basis of the EN standard, the Solar-Keymark was established in spring 2003. The clear and simple message of the Keymark is that the product complies with the European Standard(s) covering the product and therefore displays a high level of quality.

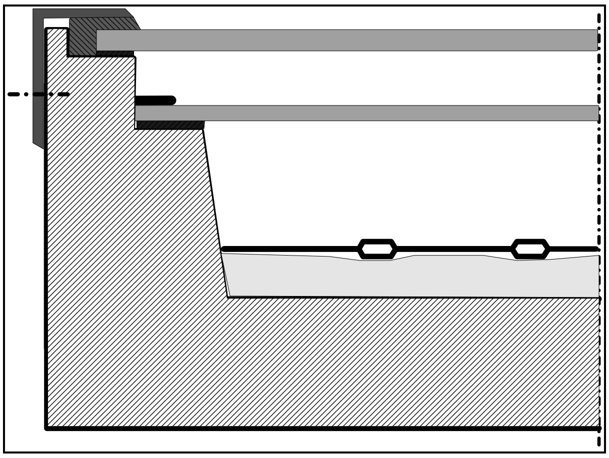
2. THE EVOLUTION OF SOLAR THERMAL COLLECTORS

Solar thermal technology is subject to continuous development and improvement. Obviously, the performance of a system relies on the performance of each individual component and the optimal arrangement of these components. For the example of the solar collector, the evolution of the technology is demonstrated from 1980 to the present. Furthermore, it is attempted to estimate the further development through the year 2010. Obviously, such estimations are based on rough assumptions of market development (size of production series, production technique) and the relative importance of material choices (ecology, price, etc.), and cannot take into account unforeseeable technical and economic developments.

2.1 Solar thermal flat plate collectors

Flat plate collectors developed around 1980:

As everyone knows, the oil crises in the seventies led to serious discussions about energy needs and the energy future. One potential solution to the energy problem was seen to be the broad application of solar energy. As a consequence, a great number of solar thermal collectors entered the market. Many of these early products had substantial weaknesses with regard to performance and quality. Sinking oil prices in the early eighties reduced the interest in solar energy and only a few products survived. Nevertheless, some of these early installations are still in operation - after more than 20 years in the field. One example is shown in the next figure.



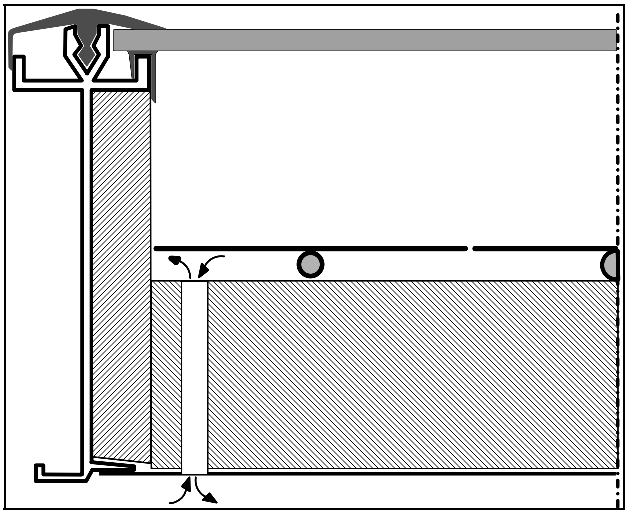
Absorber:	Aluminium rollbond absorber
Coating:	Non-spectral selective black paint
Covers:	Outer glazing: rough-structured, tempered low-iron glass Inner glazing: tempered, low-iron float glass
Insulation:	Polyurethane foam / mineral wool
Casing:	Aluminium sheet metal, the stiffness of the module is given by the polyurethane foam
Ventilation:	No ventilation

Figure 1: Solar thermal flat plate collector around 1980

This flat plate collector representative of 1980 was one of the best products sold in Switzerland between 1974 and 1988. Only a few technical improvements were instituted during that time, relating to the deformation and deterioration of the polyurethane foam due to the high stagnation temperature. In many installations, condensation formed due to lack of ventilation with ambient air. A much-discussed risk at that time was the susceptibility of the aluminium rollbond absorber to internal corrosion due to the presence of different materials in the collector loop (copper, steel, bronze …). Although the watery glycol mixtures used as heat transfer media varied greatly with regard to corrosion inhibitors, installations operated according to the manufacturer's specifications displayed almost no corrosion problems during their entire lifetime.

Flat plate collectors developed around 1990:

Remarkable improvements in collector quality and performance were realised in the years around 1990. By that time, interest in solar thermal systems was once again growing in central Europe due to public discussions on sustainability, climate change and the finiteness of conventional primary energy sources. Even though the demand for solar products increased, the production volumes of the numerous manufacturers remained very low, with collectors being mostly handmade without any automated manufacturing support.



Absorber:	Many folds with parallel absorber fins, absorber sheet metal cold rolled around the tube
Coating:	Spectrally selective absorber coating, black chrome on nickel on copper sheet metal
Cover:	Rough-structured, tempered, low-iron glass, held and sealed by EPDM profile
Insulation:	Mineral wool with laminated black fleece
Casing:	Extruded aluminium profile with sealed corner links
Ventilation:	Ventilation holes

Figure 2: Solar thermal flat plate collector around 1990

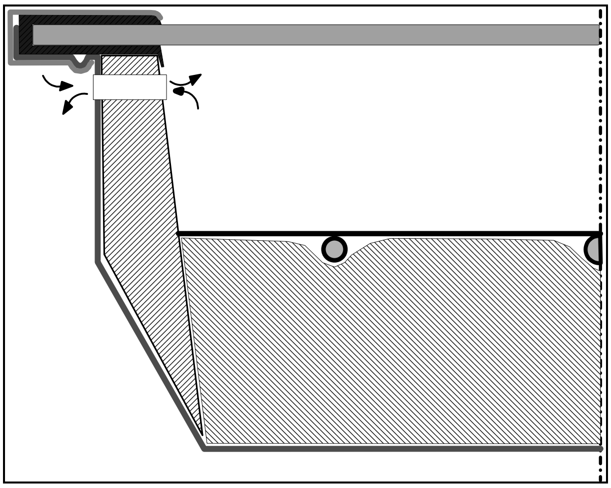
The most remarkable improvement from 1980 to 1990 was the introduction of spectrally selective solar absorber coatings in most of the collector products. The largest market share of absorber coatings was achieved by an American manufacturer of black chrome coating on a nickel plated copper sheet. Typical casings were produced using extruded aluminium profiles, allowing complicated geometries to introduce features like secondary drainage or mounting options for easy installation. As a result of extensive warranty claims resulting from water vapour condensation on the inner side of the glass cover, ventilation holes were introduced for controlled air exchange between the collector and the ambient.

A weakness of extruded aluminium profiles in casing design were the corner connections. Many products showed leakage at the corners due to bad processing or insufficient sealing materials.

Flat plate collectors developed around 2000:

In the decade between 1990 and 2000, a number of important developments in flat plate collector technology were made possible primarily due to the further increase of market volume. In central Europe, Austria and Germany played leading roles due to important subsidy programs coupled with the political will to find substitutes for conventional primary energy sources.

Due to increasing production volumes, companies began to switch from handmade fabrication to automated fabrication methods. Important results of automated fabrication were the increase in quality and the remarkable decrease of production costs.



Absorber:	Copper serpentine and headers soft soldered on a copper sheet
Coating:	Spectrally selective absorber coating, Ti/TiN_yO_X on copper sheet metal
Cover:	Fine-textured, tempered, low-iron glass, fixed and sealed by an EPDM profile and a clip-on cover rail
Insulation:	Mineral wool with laminated black fleece
Casing:	Aluminium casing trough
Ventilation	Ventilation holes

Figure 3: Solar thermal flat plate collector around 2000

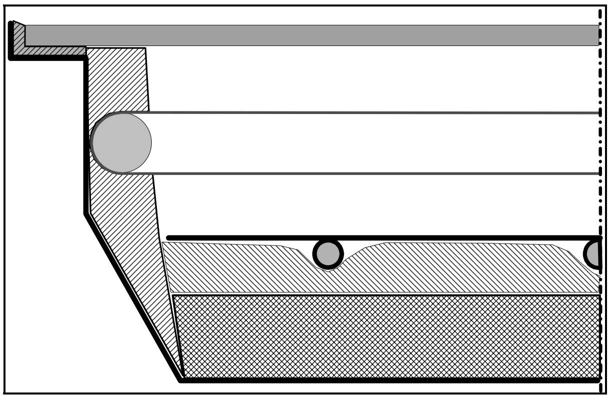
The flat plate collectors of the year 2000 displayed drastically increased performance compared to the products of 1990. The main impact was the optimisation of the collector efficiency factor (F'). Improved absorber designs and better production techniques were introduced. Also, the new spectrally selective absorber coatings made by plasma processes helped to increase performance. While the absorptance of these coatings is comparable to the absorber coatings made by galvanic processes, the emittance values are much lower and therefore help to increase performance at elevated temperatures.

Another important aspect for achieving high yearly performance is the incident angle modifier of the cover. Many of the rough pyramidal structures used showed high reflectance values at incident angles above 30°. With the help of photo-optical analysis and ray tracing calculations, the understanding of existing structures improved and better structures were proposed. Angular-dependant optical spectroscopy verified the excellent performance of the new structures.

With regard to quality and lifetime, the flat plate collectors of the year 2000 also improved. Controlled ventilation and watertight casings, including the fluid in- and outlets as well as the cover-to-casing seal became standard. Testing on the basis of international standards (EN, ISO) verified the high quality of these products.

Flat plate collectors developed until 2010:

Predicting technological evolution even for the short period of less than a decade is very difficult and can be nothing more than speculation. Nevertheless, the flat plate collector envisioned for the year 2010 is technically feasible and offers a number of improvements. The basis for achieving the proposed technical advances is a strongly growing market leading to large production runs with a very high level of automation.



Absorber:	Copper serpentine laser welded on a aluminium sheet
Coating:	Spectrally selective absorber coating, advanced PVD-coating on aluminium sheet metal
Covers:	Outer glazing: Anti-reflection treated fine-textured, tempered, low-iron glass, Inner glazings: 2 anti-reflective treated plastic foils
Insulation:	Vacuum super insulation panel, mineral wool
Casing:	Stainless steel casing trough
Ventilation:	No ventilation, Krypton gas fill

Figure 4: Solar thermal flat plate collector envisioned for 2010

The major advantage over current products is the closed casing trough with krypton gas fill. This solution prevents any condensation of water vapour within the cover system and avoids the interaction of ambient air (including pollutants) with the materials used inside the collectors. For a long lifetime, the frame density must be excellent, comparable to gas-filled insulating glazings for windows. To reduce thermal losses on the topside, the collector is triple glazed with 2 plastic foils underneath a glass cover. All 3 covers are anti-reflectively treated to maintain a high solar transmittance and a reasonably high incident angle modifier. The back side losses are reduced by introducing temperature-stable vacuum superinsulation. The laser-welded copper serpentine on a aluminium absorber sheet has an optimised collector efficiency factor of about 0.98 in the highly insulated environment. Very difficult to predict is the element size of future high efficiency collectors. There might be a tendency towards smaller element sizes of 1.5 to 2 m^2 for easy installation and integration. In addition, this would help reduce handling and transportation costs compared to modules of 2.5 m^2 and larger.

Performance of flat plate collectors from 1980 to 2010:

The performance of thermal collectors can be described basically by the efficiency curve and the incident angle modifier.

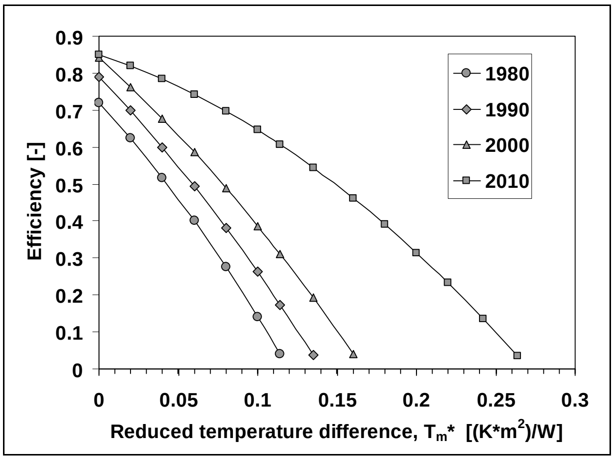


Figure 5: Efficiency curve of flat plate collectors from 1980 to 2010 for the aperture area

While the efficiency curves for the years 1980, 1990 and 2000 represent typical measured data, the data for the proposed collector are calculated. In the detailed calculation it was attempted to estimate the importance of thermal bridges, for example the in- and outlet of the absorber tubes and heat losses due to imperfect insulation at the sides of the casing trough. Experiments with gas-filled collector designs are currently in progress at SPF.

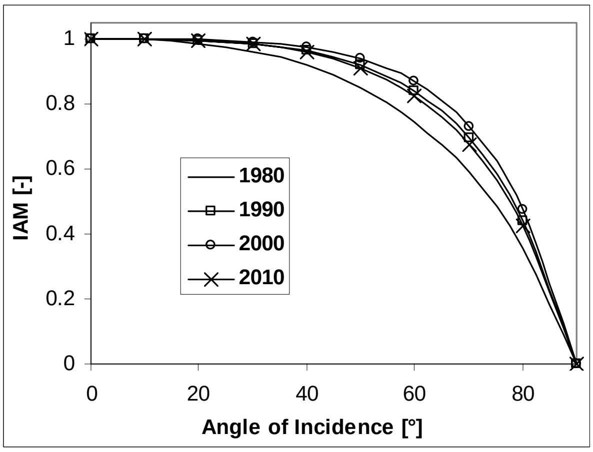


Figure 6: Incident angle modifier of flat plate collectors from 1980 to 2010

The collector of the year 2000 shows a very high incident angle modifier due to the smooth structure of the cover. Due to the triple glazing approach of the collector estimated for 2010, the incident angle modifier is significantly lower.

To demonstrate collector performance, it is much more significant to simulate the solar fraction or the yearly heat gain on the basis of typical applications. Therefore, the collectors described above have been integrated into the same simulated systems, once in a solar domestic hot water system and once in a combi system (hot water and space heating). There are two ways to illustrate the performance difference between the collectors. First, the increase in solar fraction can be simulated while maintaining the aperture surface of the collector field, and second, the decrease in necessary aperture area can be expressed to achieve the same solar fraction.

Both systems are exposed to typical central European climate (Rapperswil, Switzerland). The domestic hot water system is installed in a multi-family house with about 50 inhabitants. Their daily consumption amounts to 2500 l (50°C) and the collector field is south-oriented with a tilt angle of 30°. The combi system is installed in a energy-efficient single-family home with a yearly heating load of 5400 kWh. The daily hot water consumption is 220 l (50°C) and the collector field is south-oriented with a tilt angle of 55°.

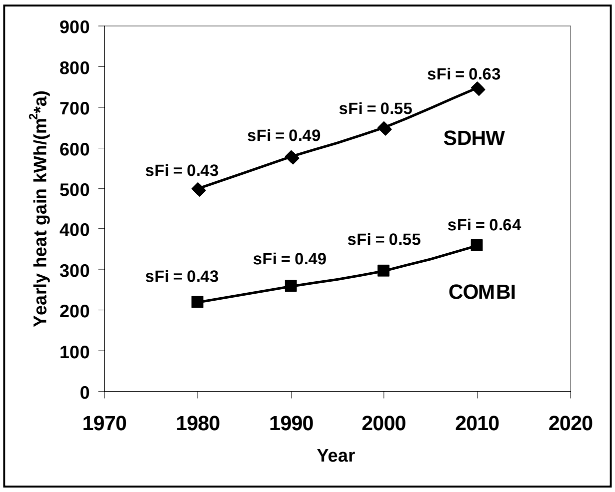


Figure 7: Specific yearly heat gain in a domestic hot water and in a combi system maintaining the aperture area of the collector field constant: 40 m^2 for the domestic hot water system, 20 m^2 for the combi system.

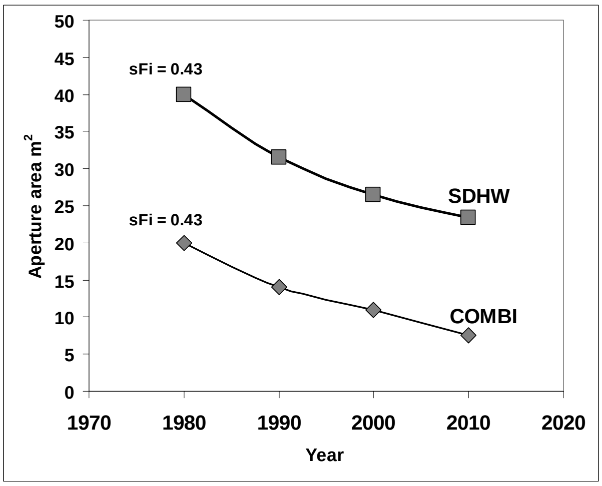
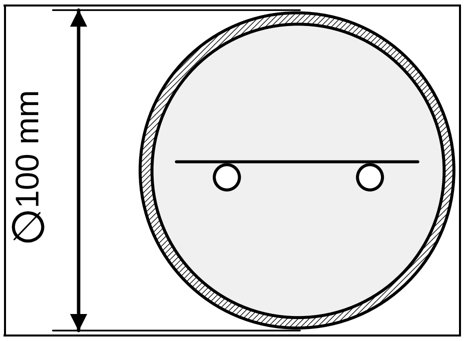


Figure 8: Decrease in necessary collector aperture area in comparison to the collector of 1980 for a domestic hot water and a combi system

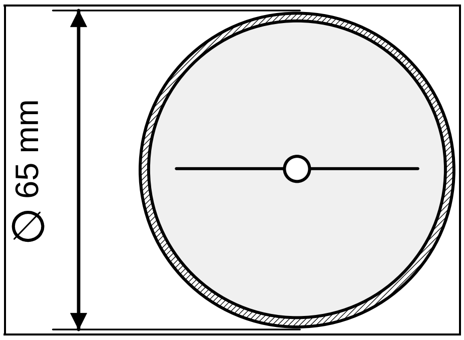
2.2 Solar thermal evacuated tubular collectors

Evacuated tubular collectors developed around 1980:

The evacuated tubular collectors around 1980 can be grouped as follows: the large 4 inch (about 100 mm) diameter tubes based on borosilicate glass and the smaller tubes with a diameter of about 60 mm normally based on low iron soda lime glass. To remove the heat from the evacuated tube, two fundamentally different approaches were used. Either the heat transfer fluid flows directly through the metallic absorber, or the absorber tube is realized as a heat pipe system.



A	"Corning"
Absorber:	Copper tubes ultrasonically welded on copper sheet metal
Coating:	Spectrally selective absorber coating, black chrome directly on copper sheet metal
Tube:	Borosilicate glass
Tube distance:	112 mm (centreline to centreline)



B	"Philips Fournelle"
Absorber:	Water filled heat-pipe steel tube threaded through steel sheet metal
Coating:	Spectrally selective absorber coating, black cobalt on steel sheet metal
Tube:	Low-iron glass
Tube distance:	87 mm (centreline to centreline)

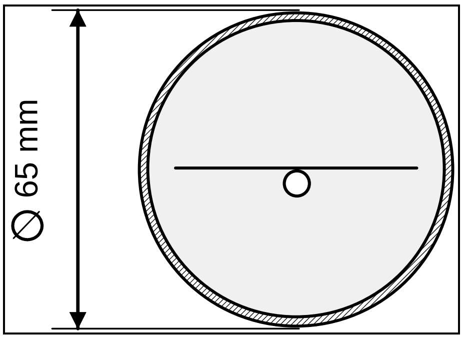
Figure 9: Evacuated tubular collectors around 1980

The early tubular collectors showed quite high performance compared to flat plate collectors of the same period. The extreme stagnation temperature of more than 250°C is especially remarkable. System designers often underestimated overheating problems, not only in stagnation but during normal operation. Many problems were caused by the incorrect selection of heat transfer media, fittings and insulation materials.

Evacuated tubular collectors developed around 1990:

The 100 mm diameter evacuated tubular collectors were implemented either as "direct flow" or as heat pipe systems. Although they have been produced by a few new companies, the market share has remained at a very low level. The reasons are the high costs, the difficulty of aesthetically pleasing architectural integration and the high requirements on the collector circuit. In the very interesting field of industrial applications, the financial aspects hindered any further acceptance of this high performance tubular collector technology.

Regarding the smaller tube diameters, the production of the original product ("Philips fournelle") has been stopped, but a new manufacturer of heat-pipe evacuated tubular collectors ("Thermomax") has appeared on the market. In order to overcome the main problem of evacuated tubular collectors, namely the extremely high stagnation temperature, this manufacturer introduced a memory-metal-based overheat protection system which stops the steam flow to the condenser when the desired maximum temperature is reached.

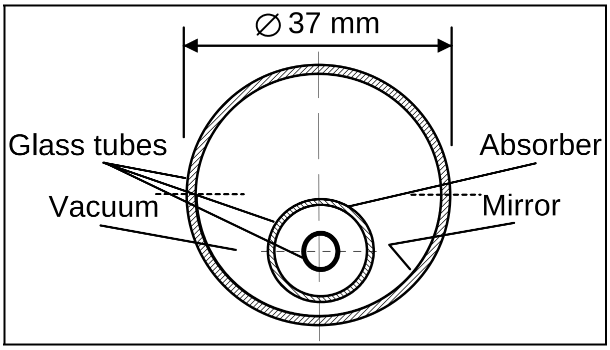


Absorber:	Alcohol filled heat-pipe, copper tube high-frequency soldered on copper sheet metal
Coating:	Spectrally selective absorber coating, black chrome on nickel on copper sheet metal
Tube:	Low iron glass
Tube distance:	71 mm (centreline to centreline)

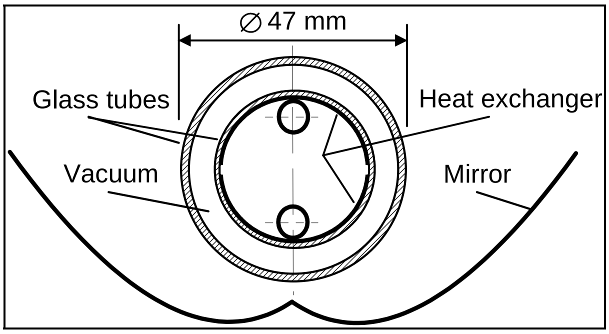
Figure 10: Evacuated tubular collectors around 1990

Evacuated tubular collectors in the year 2000:

The tubular collector market changed due to the introduction of new products and to the rapid growth of specific markets. Especially in China, the dewar type evacuated tubular collector experienced an enormous upswing with several millions of square meters being installed. Remarkably, tubular collectors now make up roughly 80 percent of the Chinese market, with flat plate collectors playing a subordinated role. In Germany, the collector market increased dramatically as a result of a nationwide subsidy program, with the market share of tubular collectors in Germany doubling to almost 20 percent in the year 2001 alone.



A	"Schott"
Absorber:	Inner glass tube
Coating:	Spectrally selective absorber coating, "Aluxid" on glass
Tube:	Borosilicate glass
Tube distance:	45 mm (centreline to centreline)



B	"Dewar-China"
Absorber:	Inner glass tube
Coating:	Spectrally selective absorber coating, aluminium in aluminium nitride on glass
Tube:	Borosilicate glass
Tube distance:	80 mm (centreline to centreline)

Figure 11: All-glass evacuated tubular collectors around the year 2000

The main feature of the new tubular collectors was the "all-glass" design. This means that the technically difficult task of sealing glass to metal (absorber / glass) was eliminated, and the risk of vacuum loss reduced. The Chinese dewar type tubes follow the principle of the well-known "Sidney-collectors". These tubes, now exported from China to many countries, allow a wide range of collector assembly designs. In many products (as the one presented here), a mirror behind the tubes enlarges the aperture area, and a heat exchanger is introduced to extract the heat from the tubes.The second all-glass collector type ("Schott") is quite different from the Chinese dewar tubes. The 2 coaxial internal absorber tubes are situated at the focus of a mirror deposited on the inner surface of the outermost glass tube. To transfer the heat from the absorber, the heat transfer media circulates through the internal glass tubes. The manifold including the sealing system is technically very demanding.

Evacuated tubular collectors in the year 2010:

Compared to the flat plate collectors, it is much more difficult to foresee the further evolution of evacuated tubular collectors. Regarding performance, the relevant materials (spectrally selective solar absorber coatings, mirrors) can be improved by a few percent. Similar to the flat plate collectors, anti-reflective treatments can be applied to the glass cover (tube). Overall though, the potential for performance improvements is smaller than for flat plate collectors. In the area of durability and reliability, a number of aspects might be investigated such as the flow distribution in collector assemblies with a large number of parallel connected tubes, the temperature stability of connection fittings and hail impact resistance of the glass tubes.

Performance of evacuated tubular collectors from 1980 to 2000:

The performance of thermal collectors can be described basically by the efficiency curve and the incident angle modifier. Especially for evacuated tubular collectors, the reference area is a much-discussed theme. For a comparison of different evacuated tubular collectors, the aperture area as described in international standards is not meaningful. For tubular collectors without mirrors, the simple product of the inner glass tube diameter times the length of the absorbers times the number of tubes does not take into account the influence of tube spacing on the incident angle modifier. The relevant area proposed here is the product of the tube spacing (tube centreline to tube centreline) times the number of tubes. This area also allows the meaningful comparison of evacuated tubular collector designs with and without mirrors. This newly defined aperture area is used here in the further discussion.

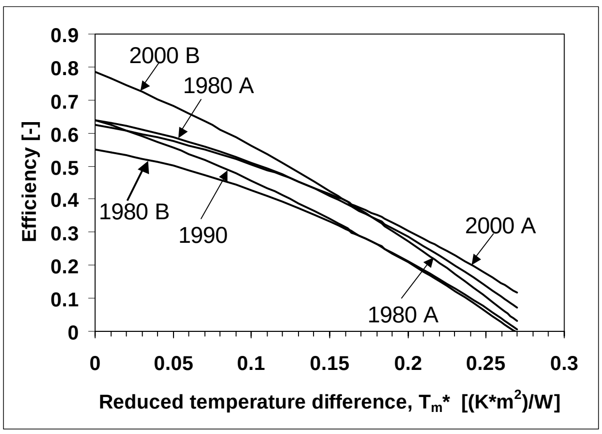


Figure 12: Efficiency curve of evacuated tubular collectors from 1980 to 2000 for the aperture area

The efficiency curves for the years 1980, 1990 and 2000 represent typical measured data.

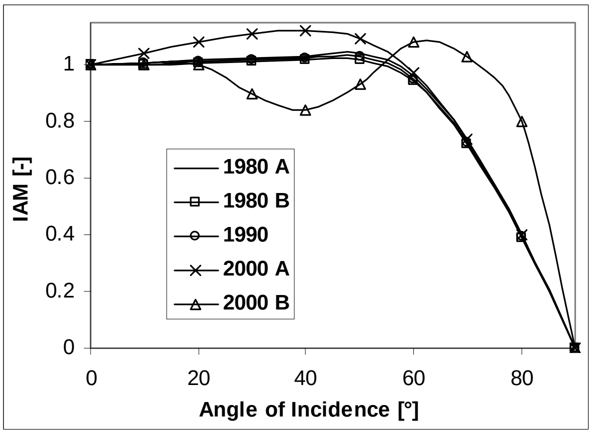


Figure 13: Incident angle modifier of evacuated tubular collectors from 1980 to 2010

To demonstrate the collector performance, it is much more significant to simulate the solar fraction or the yearly heat gain on the basis of typical applications. Therefore the collectors described above have been integrated into the same simulated systems, once in a solar domestic hot water system and once in a combi system (hot water and space heating). There are two ways to illustrate the performance difference between the collectors. First, the increase in solar fraction can be simulated while maintaining the aperture surface of the collector field, and second, the decrease in necessary aperture area can be expressed to achieve the same solar fraction.

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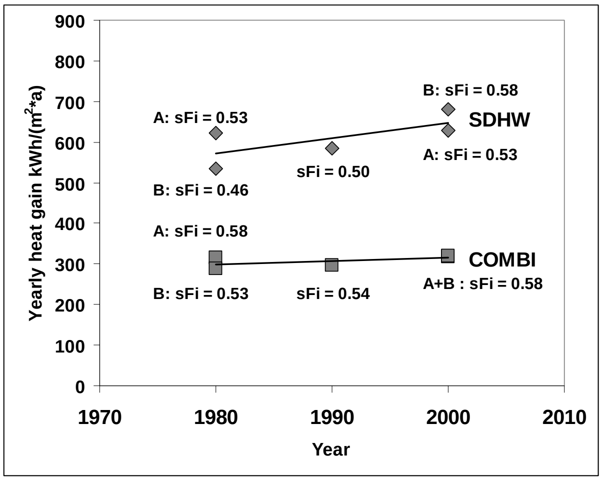

Figure 14: Specific yearly heat gain in a domestic hot water and in a combi system maintaining the aperture area of the collector field constant: 40 m^2 for the domestic hot water system, 20 m^2 for the combi system.

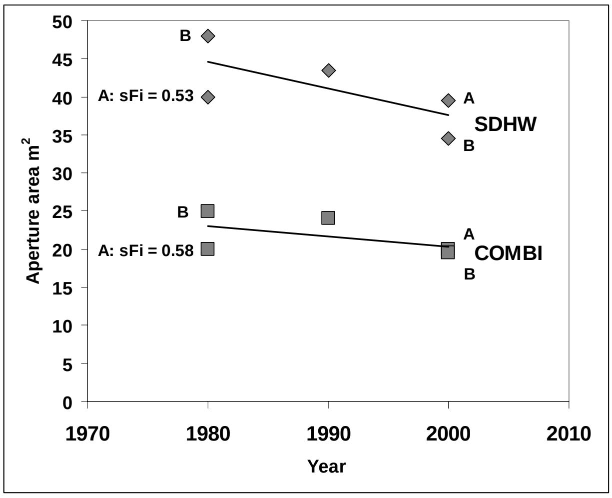

Figure 15: Decrease in necessary collector aperture area in comparison to the collector of 1980 (reference collector type A) for a domestic hot water and a combi system

2. COMPARISON OF THE PERFORMANCE OF FLAT PLATE AND TUBULAR COLLECTORS OF THE YEARS 2000 AND 2010

The differences in performance between flat plate and tubular collectors is an oft-discussed theme. Depending on the application and the specific boundary conditions, the performance difference between the two collector types may be very small (for example domestic hot water systems with low solar fractions) or very large (if higher temperatures are required).

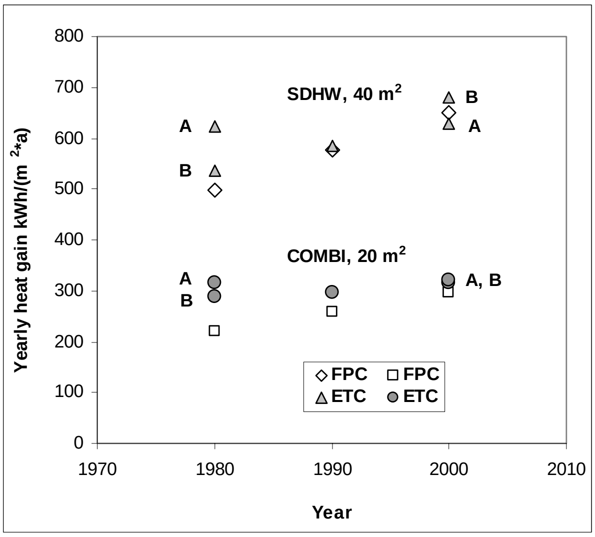

Figure 16: Comparison of flat plate and tubular collectors

3. CONCLUSIONS

The evolution of flat plate collectors has been truly remarkable. The design of the 1980's era collectors cannot be compared with current products, which offer dramatically increased quality and performance. Nevertheless, new materials, highly optimised designs and large-scale automated production all provide significant potential for further increases in performance.

Evacuated tubular collectors of the 1980's already displayed quite a high level of performance. Relative to flat plate collectors, performance improvements over the past 20 years have been less pronounced. Although new designs, including mass-produced all-glass products, are entering the market, the potential for further improvement is smaller than for flat plate collectors. However, high-performance materials and better designs will undoubtedly lead to more efficient products.

With the continuous optimisation of flat plate collectors, the performance gap relative to evacuated tubular collectors has been steadily reduced. This trend is predicted to continue in the years ahead.

REFERENCE

/1/ SPF-Info-CD, Solar collector database, measurements, design and construction details on more than 150 products, available under www.solarenergy.ch, Rapperswil.