Stainless Steel and Solar Energy in Building Applications

ISSF
INTERNATIONAL STAINLESS STEEL FORUM

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for

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Summary

In view of the increasing application of solar systems worldwide, the aim of this report is to give an overview of the state of the art regarding solar systems and possibilities for the application of stainless steel in this context.

When solar systems are being considered, distinctions are drawn between energy saving and storage systems, passive solar systems, active solar thermal and photovoltaic systems. In this report the investigation is focussed on those solar elements that are part of the building envelope.

Possibilities for the application of stainless steel can be found in nearly all the solar systems mentioned in this report. But there are clear differences that should form the basis of future decisions concerning the presentation of these solutions to the respective regional markets. These differences mainly concern the following aspects:

- the estimated quantities of stainless steel that could be applied in the system in question,
- the estimated results of research and development already available for alternatives using stainless steel for the system in question,
- the estimated market acceptance for system alternatives on the basis of stainless steel,
- the estimated cost efficiency of stainless steel in the specific system in comparison with other materials in the same application.

Taking this into account, there are some systems which are particularly suitable for the application of stainless steel. In particular, combinations of systems should be taken into consideration. With regard to the effort and expense required, system development and marketing activities are regarded as promising in

- passive systems, e.g. greenhouse and glass roof systems, with regard to quick realization, including system design and design tools;
- photovoltaic systems, e.g. photovoltaic façade systems that would require some development activities and system design;
- solar thermal and heat storage and protecting systems, e.g. vacuum insulation, transparent heat insulation and phase-changing thermal storage systems, which will require greater effort and expense in basic research, development of building elements and system design.

Any decisions made should take account of the fact that the possibilities vary depending on the know-how and significance of enterprises. Some of the systems can be developed with reasonable effort and expense by a single enterprise, whereas others require a team that includes capacities for basic research, the development and testing of elements, system design and manufacturing. This report will provide the basis for discussion and decision-making with regard to these aspects.

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1. Initial Position

In view of the increasing application of solar systems, not only in central Europe, the aim of this report is to give an overview of the state of the art regarding solar systems and to show possibilities for the application of stainless steel in this context.

1.1 Stainless Steel

The main characteristics of stainless steel, with regard to its application in solar systems, include the following:

- excellent corrosion resistance,
- great strength and good weldability,
- good formability, especially in the form of sheets and foils,
- low thermal conductivity compared to other metals,
- low elongation due to heat (thermal expansion).

The potential for the application of stainless steel in solar systems should be evaluated with the focus on these characteristics.

Fig. 1: Approximate properties of materials applied in solar systems

	Stainless steel	**Steel**	**Copper**	**Zinc**	**Alumin-ium**
Apparent specific gravity, density [kg/dm³]	7.7 – 8.0	7.87	8.96	7.14	2.69
Modulus of elasticity, stiffness [kN/mm²]	200 – 220	210	132	90	65
Thermal expansion 20 °C – 100 °C [10 K^{-1}]	10.0 – 16.5	12,0	16.8	36	23.8
Heat conduction, ther-mal conductivity [W/(m*K)]	15 – 25	40 – 60	401	116	160
Specific heat capacity [J/(kg*K)]	460 – 500	460 – 480	385	388	900
Weather resistance [+++ very good, ++ good, o low]	+++	o	++	++	++
Melting point [°C]	1,500	1,536	1,083	419	660

1.2 Solar Energy Use in Buildings

In anticipation of possible shortages of primary energy sources (e.g. oil, coal, gas, uranium) and with environmental awareness increasing, the use of solar energy has had remarkable growth in recent years, especially in central Europe but also in other countries. Some data from the German market (the capacity of annually installed thermal and photovoltaic systems) may explain this growth:

Fig. 2: Development of solar systems installed annually in Germany (BSW and hwp)

Solar thermal systems (Germany) *conversion factor 0.7 MW_{th}/1,000 m²*	1995 2000 2005	150 MW_{th}/a 430 MW_{th}/a 660 MW_{th}/a	215,000 m²/a **620,000** m²/a **950,000** m²/a
Photovoltaic systems (Germany) *conversion factor 0.1 MW_p/1,000 m²*	1995 2000 2005	6 MW_P/a **44** MW_P/a **850** MW_P/a	60,000 m²/a 440,000 m²/a 8,500,000 m²/a

Even though the German market is a particularly positive example, other countries will follow in a similar way because they have the same problems. It is self-evident that there will be differences that reflect the characteristics of countries depending on e.g. the climate and the degree of industrial development. But the general trend will be the same.

For an easier understanding of the following statements concerning quantities, simplified conversation factors are given in Fig. 3.

Fig. 3 Simplified conversion factors between area and capacity

Systems (degree of effectiveness)	**Area**	**Capacity**
Solar thermal systems (η ≈ 0.8)	1.0 m²	0.8 kW_{th}
	1,000.0 m²	800.0 kW_{th} – 0.8 MW_{th}
	1.25 m²	1.0 kW_{th}
	1,250 m²	1,000 kW_{th} – 1.0 MW_{th}
Crystalline photovoltaic systems (η ≈ 0.1)	1.0 m²	0.1 kW_p
	1,000.0 m²	100.0 kW_p – 0.1 MW_p
	10.0 m²	1.0 kW_p
	10,000.0 m²	1,000.0 kW_p – 1.0 MW_p
Thin film photovoltaic systems (η ≈ 0.05)	1.0 m²	0.05 kW_p
	1,000.0 m²	50.0 kW_p – 0.05 MW_p
	20.0 m²	1.0 kW_p
	20,000.0 m²	1,000.0 kW_p – 1.0 MW_p

Annual growth rates in the area of thermal and photovoltaic solar systems are shown for selected countries in Fig. 4 and Fig. 5 as realized in 2005 and expected for the year 2010.

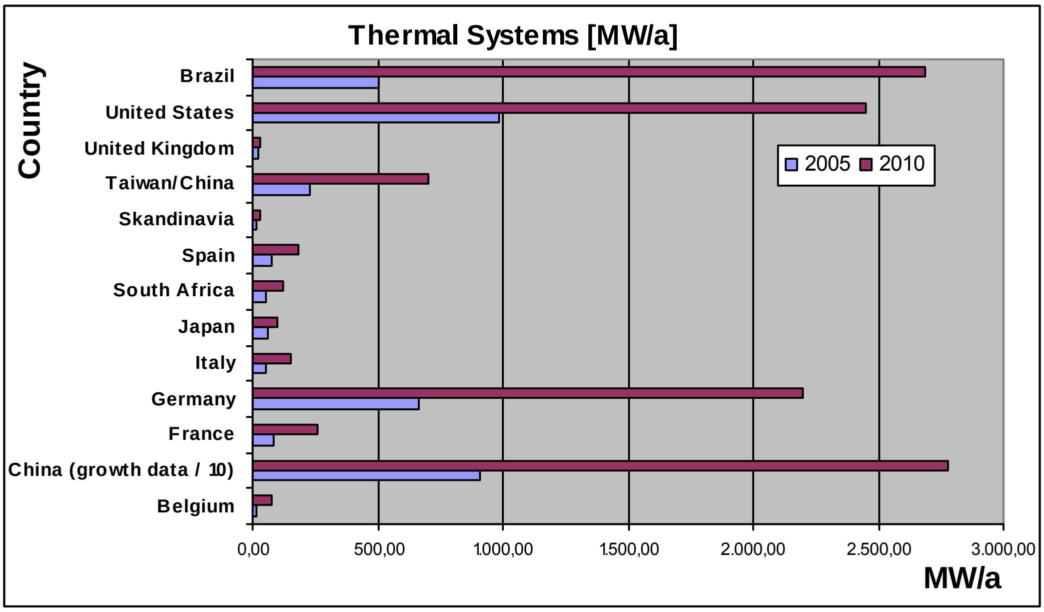


Fig. 4 *Annual growth data in terms of newly installed capacity for solar thermal systems in selected countries. In this graph a conversion factor of 0.8 MWth/1,000 m² is used.*

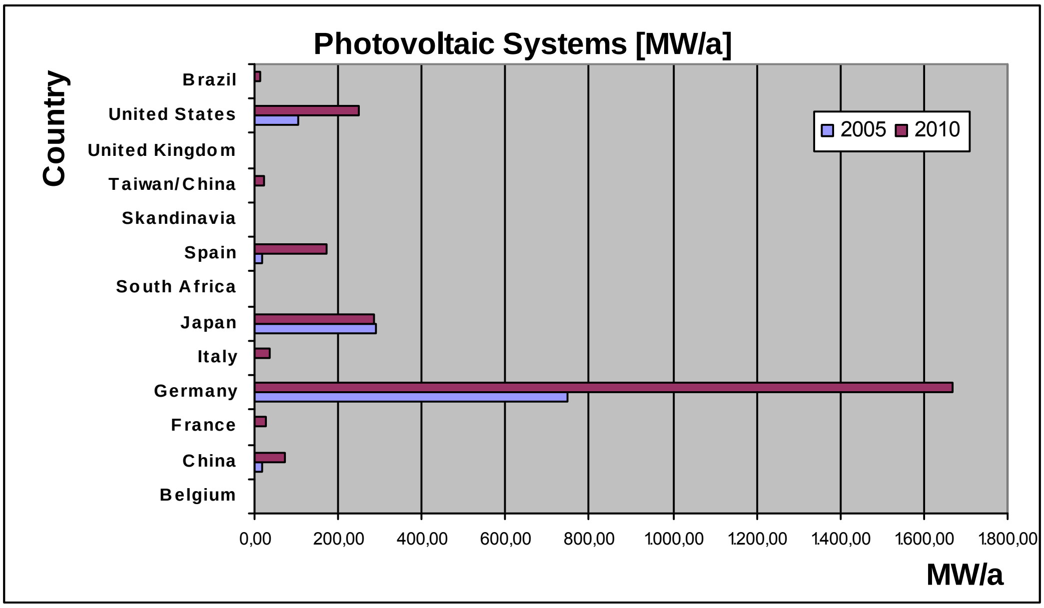


Fig. 5 *Annual growth data in terms of **capacity** for photovoltaic systems newly installed in selected countries. For crystalline photovoltaic systems, 1 MW_p corresponds to a module area of about 10,000 m².*

The worldwide trend with regard to the energy mix is shown in Fig. 6. By the end of this century the share of renewable energy consumption in the worldwide mix is expected to be more than 80 %. Solar systems (thermal and photovoltaic, central and decentralized) are expected to comprise the bulk of the renewable energy systems.

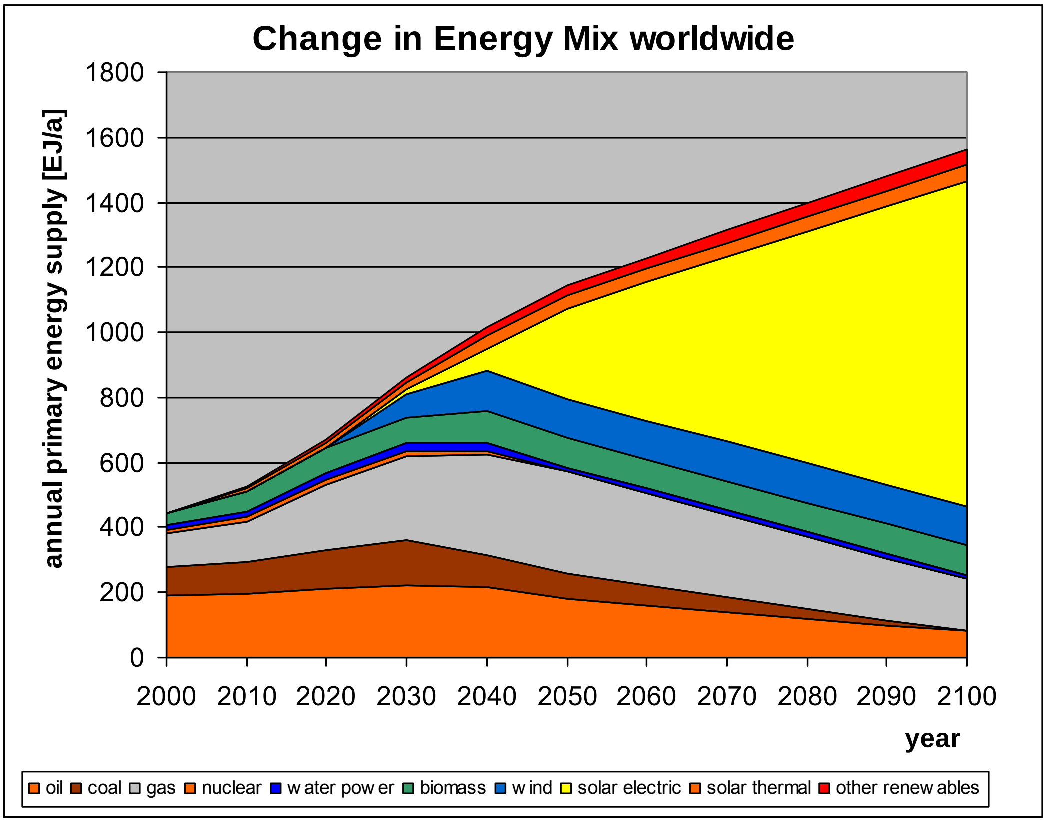


Fig. 6 *Change in **energy mix** worldwide up to the year 2100 in EJ/a (Exa-Joule = 10^{18} Joule) as assumed in the forecast by the scientific committee of the German Federal Government (hwp according to BSW)*

2. Solar Systems and Stainless Steel

Solar systems can be classified by the following technologies that they use, as shown in the table on the next page:

- **heat saving systems** – i.e. in this context particularly the saving of thermal energy in the building structure but also the saving of heat from solar radiation in solar thermal systems,
- **heat storage systems** – i.e. particularly systems for storing thermal energy in water tanks or in encapsulated phase-changing materials,
- **passive solar systems** – i.e. systems for passive heating and cooling by solar radiation solely by means of the building structure (transparent elements as radiation traps, monolithic building elements such as walls and floors as heat storage),
- **active solar thermal systems** – i.e. systems for the active heating and cooling of interiors and hot water heating by means of technical systems based on solar collectors, heat accumulators and heat pumps);
- **active photovoltaic systems** – i.e. systems for the direct conversion of light to electricity by solar cells, modules and generators.

In this report, the investigation is focussed on those elements of solar systems that are more or less part of the building's "skin" or "envelope" in the form of roof or façade elements. Technical devices like inverters, heat pumps, accumulators, etc., as well as machinery, could be the subject of a separate study.

The assessment given for the application of stainless steel in the systems mentioned in this report will be mainly qualitative. If quantitative statements on the potential applications of stainless steel are to be made, a more detailed investigation should be undertaken.

It seems to be very important that promising starting points for future development and the application of stainless steel in solar systems are combinations of single systems. In such procedures, genuinely new systems and synergetic effects can be realized.

In most cases the different materials mentioned in Fig. 1 compete for the same application. The goal of future development should be to find out the advantages of stainless steel for the applications discussed and also to find technically and economically reasonable solutions involving possible combinations of different materials.

Systems can be categorized by different types of application as listed below:

corresponding to the degree of **building integration**, e.g.

- **additional to buildings** (no integration),
- **connected to buildings** (partly integrated),
- **building elements** (full integration).

corresponding to **building functions**, e.g.

- **residential buildings** (sanitary hot water, room heating, electricity generation),
- **commercial and office buildings** (sanitary hot water, room conditioning, cooling, drying, electricity generation),
- **industrial buildings** (sanitary hot water, drying, electricity generation)
- **transport service buildings** (e.g. airports, railway stations) (electricity generation, radiation shielding, daylighting, shading),
- **sports centres** and swimming pools (sanitary hot water, pool heating),
- buildings with **special functions** (e.g. airport towers, petrol stations) (electricity generation, radiation shielding, shading),
- solar thermal and photovoltaic **energy plants**.

The basic categories of solar systems related to building integration are presented in Fig. 7.

Fig. 7: Basic categories of solar systems. The numbers in () indicate the chapter in which the description of the system can be found.

	Heat saving and heat storage systems (2.1)	Passive solar systems (2.2)	Active solar thermal systems (2.3)	Active photovoltaic systems (2.4)
State-of-the-art building-integrated	frames for windows, doors and façades (2.1.1)	thermal storage wall systems (2.2.1)	low temperature absorber systems (2.3.1)	photovoltaic roof elements and systems (2.4.1)
	insulated façade elements (2.1.2)	shading devices (2.2.2)	solar collector systems (2.3.2)	photovoltaic façade elements and systems (2.4.2)
	insulated roof elements (2.1.3)	daylighting systems (2.2.3)	active solar facades (2.3.3)	
		greenhouse systems (2.2.4)		
		solar façades (2.2.5)		
State-of-the-art building independent	vacuum insulation (2.1.4)		solar stoves (2.3.4)	reverse side foil cover (2.4.3)
	phase-changing thermal storages (2.1.5)		concentrating thermal systems (2.3.5)	concentrating photovoltaic systems (2.4.4)
			substructures for thermal collectors (2.3.6)	substructures for PV arrays (2.4.5)
			active solar cooling systems (2.3.7)	
Basic development		transparent heat insulation (2.2.6)		substrates for thin film photovoltaic cells (2.4.6)
		passive solar cooling systems (2.2.7)		substrates for organic and dye pv cells (2.4.7)

2.1 Stainless Steel in Energy Saving and Storage Systems

2.1.1 Frames for Windows, Doors and Façades

General State of the Art

Common materials for window and door frames are timber, plastic materials and metals, particularly aluminium. Due to thermal requirements, metal frames need a thermal separation of interior and exterior parts of the frame.

Fig. 8: Stainless steel frames in an office building façade (AEGIS Hannover, ARCASA).

Fields of Application for Stainless Steel

Stainless steel is highly suitable for window and door frames due to its corrosion resistance and its high-tech image in the field of high-quality facades, e.g. in office buildings. Its application could be improved by systems of even better thermal quality, e.g. passive house standard ($U \leq 0.15$ $W/(m^2{*}K)$).

Here a combination of different materials, e.g. for high thermal insulation, will be useful.

2.1.2 Insulated Façade Elements

General State of the Art

Insulated façade elements are used mainly in the form of sandwich elements in non-ventilated wall constructions. Covering materials are metals as well as fibre concrete or special plastic materials. For the insulating core material, organic foam (e.g. polyurethane) is generally applied.

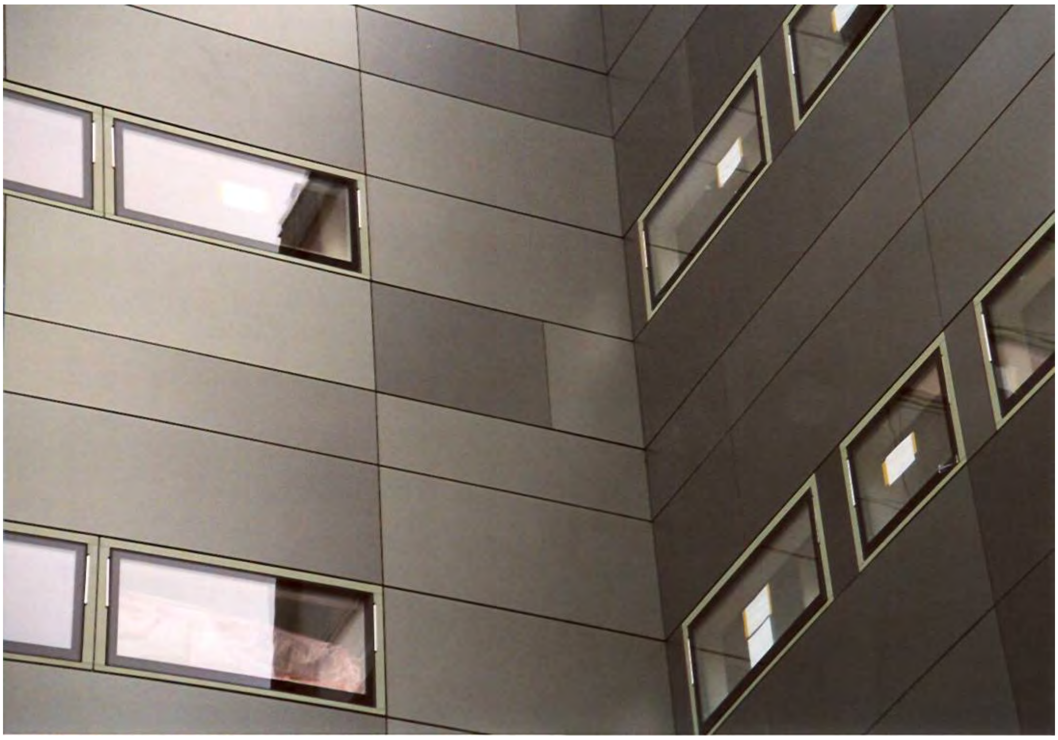


Fig. 9: Insulated façade element in a curtain wall façade (AEGIS Hannover, ARCASA).

Fields of Application for Stainless Steel

For high-quality façades, insulated sandwich elements with a stainless steel outer layer are fabricated on demand. The main reasons for the application of stainless steel are its corrosion resistance and high-tech appearance.

A further improvement in the thermal characteristics could be achieved through a combination with materials of low thermal conductivity or even with → vacuum insulation (2.1.4) to obtain maximum thermal insulation values in combination with a minimum thickness of the insulation element.

The combination with → phase-change material elements (2.1.5) could give to the lightweight construction the properties of a massive construction because of retardation of the heat transmission.

2.1.3 Insulated Roof Elements

General State of the Art

Insulated roof elements are used as sandwich elements in non-ventilated pitched roof constructions. Covering materials are mainly metals (e.g. galvanized and coated steel or aluminium). For the insulating core material, organic foam (e.g. polyurethane) is applied.

Fig. 10: Large insulated roof element (Hoesch-Contecna).

Fields of Application for Stainless Steel

Thermal characteristics can be improved by combination with → vacuum insulation (2.1.4) and with → phase-change material (2.1.5).

There are also possibilities of application for roof elements with exceptionally high life expectancies thanks to the corrosion resistance of stainless steel.

Combination with → photovoltaic modules (2.4.1) is also a promising concept.

2.1.4 Vacuum Insulation

General State of the Art

Compared to traditional thermal insulating materials, vacuum insulation offers considerably better insulation properties in combination with low element thickness. A high life expectancy requires corrosion resistance, absolute tightness and good weldability. Following prior technical applications (e.g. cold storage) we now have the first examples of application in building elements.

Fig. 11: Vacuum insulation integrated into light wall constructions (VARIOTEC).

Fields of Application for Stainless Steel

Stainless steel was the first wrapping material in vacuum systems. Plastic materials in combination with metal foils are being applied in new products.

Stainless steel elements with vacuum insulation for high-quality façades could become high-tech building elements. To avoid thermal bridges in joints, this aspect should be a major field of system development.

2.1.5 Phase-Changing Thermal Storage

General State of the Art

Whereas thermal accumulators of water, stones or concrete change their temperature depending on the quantity of accumulated heat, phase-changing materials use the phase change (solid to liquid or vice versa) for accumulating or releasing thermal energy at a constant temperature. Salts (e.g. sodium sulphate or sodium acetate) or paraffin are applied as phase-changing materials (PCM).

These materials can be arranged in containers with heat exchangers or in small quantities encapsulated in small plastic balls or between foils. To store a certain quantity of thermal energy, latent heat storage needs only 1/5 of the volume that water storage needs in a defined temperature range.

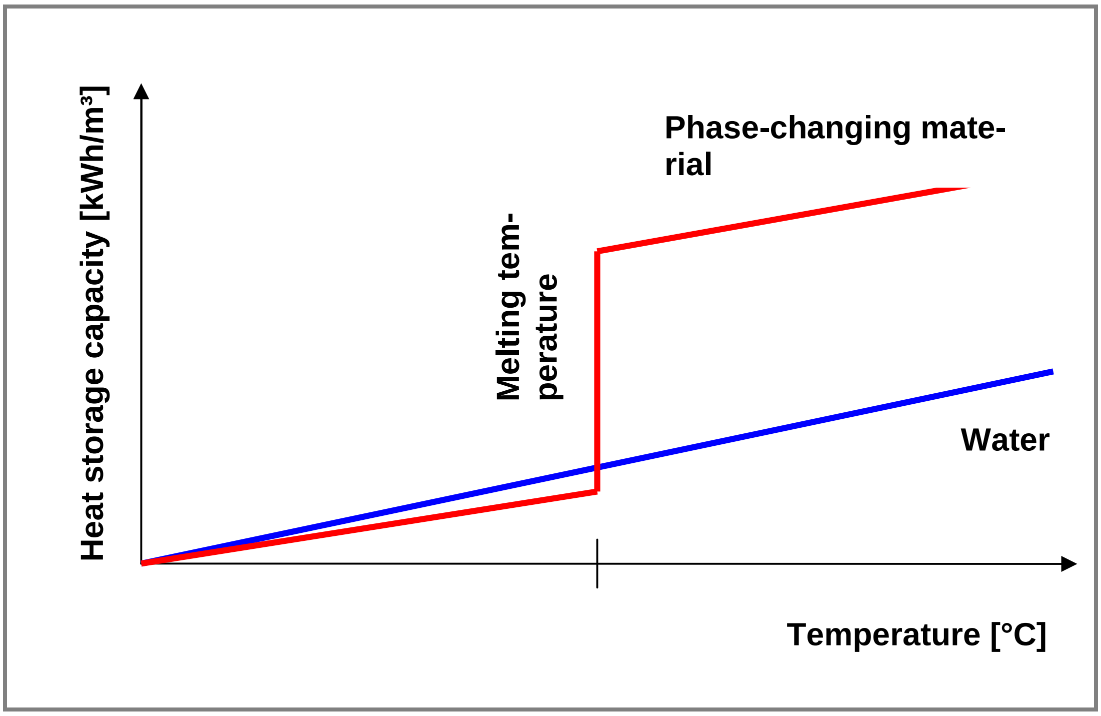


Fig. 12: Schematic comparison of heat storage capacity between water and phase-changing material (PCM, e.g. sodium acetate).

Fields of Application for Stainless Steel

Salts as PCM, in particular, require non-corrosive materials for containers and for encapsulating. Other materials, e.g. paraffin, have to be protected because of their fire characteristics.

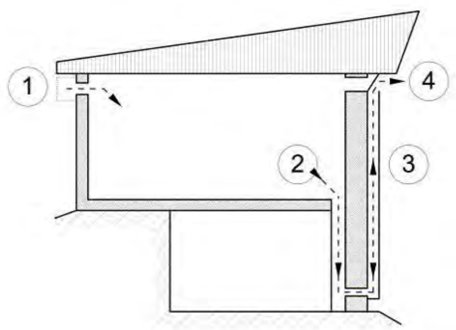
Particularly in the case of integration of phase-change thermal storage systems in building constructions, a highly corrosion-resistant encapsulation is very important.

2.2 Stainless Steel in Passive Solar Systems

2.2.1 Thermal Storage Wall Systems

General State of the Art

Initially, solar thermal storage systems in buildings consisted of brick or concrete walls, covered by glass on the outside. This system, well known as “Trombe Wall”, is very simple and inexpensive. But it is also difficult to control. In this example dating from the 1960s, the storage wall consists of 40 cm of concrete. For current and future application it could be replaced by panels with phase-change materials in combination with a layer of vacuum insulation on its inner side.



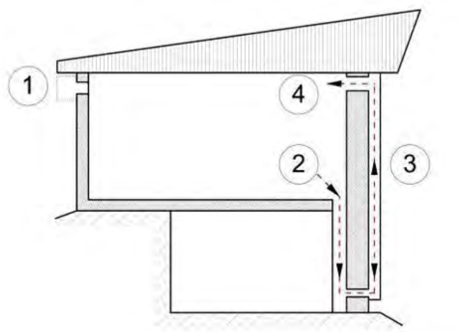


Fig. 13: Thermal storage wall (“Trombe Wall”). Cooling in summer operation (top) and heating in winter (bottom).

1 Cool fresh air entry in summer, closed in winter (north side).
2 Room air out.
3 Air warmed between storage wall and outer glass pane (south side).
4 Outlet for warm air in summer, entry for warm air in winter.

Fields of Application for Stainless Steel

The application of → phase-changing materials (PCM, 2.1.5) integrated in stainless steel envelopes instead of bricks or concrete could allow light-weight constructions with the thermal capacity of a concrete wall to be controlled even better.

A combination with → vacuum insulation (2.1.4), → transparent heat insulation (2.2.6) and → shading devices (2.2.2) would be able to improve control conditions significantly.

2.2.2 External Shading Devices

General State of the Art

In high-quality façades and transparent roofing, shading devices are necessary to protect rooms from overheating. There are fixed as well as movable shading devices.

Fig. 14: External shading devices (solarnova)

Fields of Application for Stainless Steel

Fixed and movable devices are made of stainless steel in high-quality buildings such as office or museum buildings. This also applies to shading devices with photovoltaic modules or in combination with → daylighting systems (2.2.3).

2.2.3 Daylighting Systems

General State of the Art

The purpose of daylighting systems is to control daylight in rooms. This means shading as well as conducting daylight to parts of the room far from the window. Elements of daylighting systems are reflecting devices in windows or façades as well as diffuse reflecting ceilings and light-conducting elements between glass window panes or glass roofs.

Fig. 15 Daylighting systems: prismatic louvers (top left), vertical metallic louvers (top right) and vertical daylighting devices (BKK Schwenningen, bottom) (COLT BOMIN SOLAR)

Fields of Application for Stainless Steel

Fixed and movable devices made from stainless steel are applied on demand in high-quality buildings, such as office or museum buildings. There are possibilities for combining those devices with → shading devices (2.2.2) or → tracking photovoltaic systems (2.4.2). Reflecting and light-conducting devices between glass panes are also known.

2.2.4 Greenhouse and Atrium Systems

General State of the Art

Initially, greenhouses were merely simple constructions in the horticultural segment. Increasing demand for the thermal optimization of buildings developed them into elements of passive solar systems in buildings of high thermal quality. They range from small winter gardens in residential buildings to large glazed atrium and envelope constructions (house in house). The first are constructed with wooden or aluminium profiles, while the latter require more sophisticated constructions for load transfer and for the fastening of glass panes.

Fig. 16: Atrium Glazing: Strasbourg central station (top and bottom left), Strasbourg Modern Art Museum (bottom right) (seele)

Fig. 17: Winter garden (left) and atrium glazing (right) in combination with semi-transparent photovoltaic roof elements (solarnova).

Fields of Application for Stainless Steel

Requirements of corrosion resistance and low maintenance suggest the application of stainless steel for profiles as well as for load-bearing elements.

2.2.5 Solar Façades

General State of the Art

There are many functions in solar facades. One of them is to get heat from solar radiation for room heating or cooling, hot water preparation by heat exchanger, heat pumps or even cooling by thermal refrigeration units.

Major elements in the façade are control devices for the air, absorbers to transform solar radiation into heat and to transfer it to a liquid (in a thermal absorber) or to air (e.g. by woven fabric of stainless steel wire arranged in the ventilated space of a glass façade).

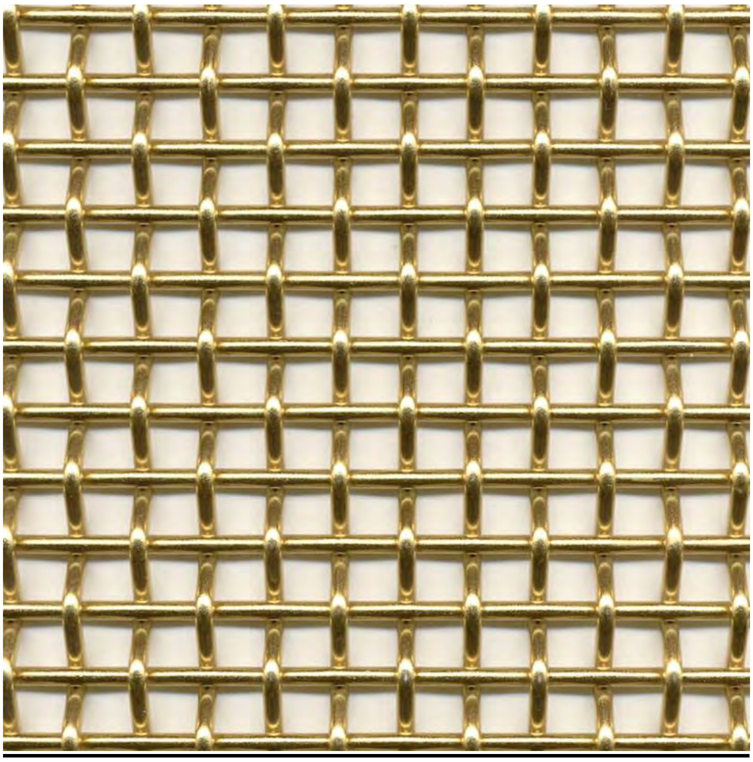


Fig. 18: Stainless steel woven fabric suitable for application of energy transformation of radiation to air in solar façades (Doka-Mono 1771 gold, Haver & Boecker)

Fields of Application for Stainless Steel

The metal façades presented in the figures of this chapter in reality are not yet solar, but all of them have the chance to be. They could be equipped e.g. with solar thermal absorbers or with heat exchange functions to gain heat from solar radiation.

Stainless steel solar absorbers (solar radiation to steel, heat conduction liquid) are applied as well as sheets, woven fabric or expanded mesh (solar radiation to woven fabric, heat conduction to air).

The development of complete solar façade systems in combination with design tools could support the application. Stainless steel woven fabric or expanded mesh can be used as well and simultaneously to produce publicity effects.


Fig. 19: Metal façades by Frank O. Gehry: Guggenheim-Museum, Bilbao, titanium (hwp, left) and Neuer Zollhof Düsseldorf, stainless steel (Melanie Charlet, right).

Fig. 20: Woven fabric to produce publicity effects (kettingstraat scherm (11): Archipelontwerpers)

2.2.6 Transparent Heat Insulation

General State of the Art

Transparent heat insulation elements generally consist of transparent but effective heat insulating materials, e.g. plastic honeycomb structures encapsulated between panes of glass. Their effect is to let solar radiation pass and heat a heat accumulator on the inside. The honeycomb structures can also be applied for daylighting.

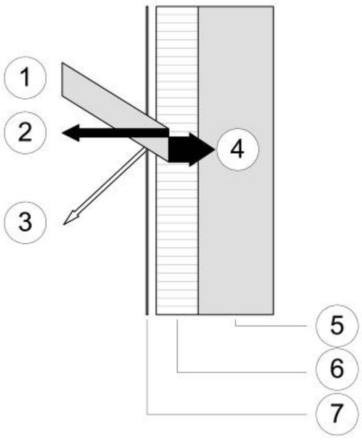


Fig. 21: Principal function of transparent heat insulation (bottom): solar radiation passes the insulation and heats a heat accumulator on the inside. The heat input and the heat transfer are shown. Transparent honeycomb structure (TIMaxCA, Wacotech, top).

1	*Solar radiation*
2	*Convective heat losses*
3	*Reflected radiation*
4	*Heat gain*
5	*Heat accumulator, e.g. brick wall or PCM*
6	*Transparent insulation*
7	*Glass pane*

Fields of Application for Stainless Steel

It would be worth investigating honeycomb structures of stainless steel foils for their properties of light conduction and heat insulation compared to those of plastic materials.

Combination with other systems could lead to new fields of application (e.g. → daylighting systems (2.2.3), → solar façades (2.2.5, 2.3.3), → phase changing thermal storage (2.1.5), → absorber systems (2.3.1), → solar stoves (2.3.4)).

2.2.7 Passive Solar Cooling Systems

General State of the Art

On clear nights, the surfaces of roofs emit infrared radiation to the cloudless (cold) sky and are thereby cooled at below the temperature of the ambient air. Passive solar cooling systems use this fact by taking this coolness from the roof surface and transporting it to a (cold) thermal storage facility. From here it can be given to e.g. a cooling ceiling in case of demand the following day.

Demonstration plants showed that a specific cooling performance of 100 W/m² is attainable.

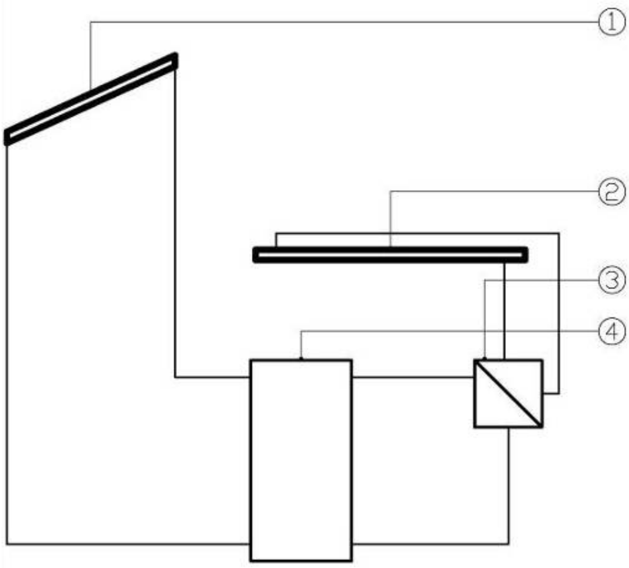


Fig. 22: Passive solar cooling with uncovered collector, thermal store and cooling ceiling

1 Roof integrated uncovered collector
2 Cooling ceiling
3 Heat exchanger
4 Cold thermal storage

The main component of this system is the uncovered collector. It may be a weatherproof roof surface as well as a collector with a flow-through of a heat transporting liquid.

Fields of Application for Stainless Steel

Uncovered solar collectors can be integrated into roofs as already described in → (2.3.1) and → (2.3.2).

It is possible with a special system design (two separate thermal storages) to collect solar heat during the day as well as coldness during the night.

We expect reasonable market potential for residential applications in warm climates. Compared to competing materials, stainless steel offers the additional advantage of extremely high weather resistance.

2.3 Stainless Steel in Solar Thermal Systems

2.3.1 Low Temperature Absorber Systems

General State of the Art

Low temperature absorbers are generally not covered with glass. This means that they are also able to collect thermal energy from solar radiation as well as from the ambient air. Fields of application are the collection of thermal energy for direct use, e.g. in swimming pools, and the production of mid-temperature thermal energy with heat pumps. Common materials are sheet metal and plastics.

Fig. 23: Building-integrated low-temperature stainless steel thermal absorber in façades (top, Frei) and in roofs (bottom, Energie Solaire).

Fields of Application for Stainless Steel

Stainless steel solar absorbers can be integrated into roofs and façades.

Requirements of corrosion resistance, high life expectancy, low maintenance and high aesthetical requirements suggest the application of stainless steel.

2.3.2 Solar Collector Systems

General State of the Art

Solar collectors are constructed to transform solar radiation into heat up to the boiling point of water. They consist of an absorber, heat insulation, transparent covering and a frame. Heat insulation is the essential criterion for the level of temperature. As a result, collectors with insulation by vacuum (vacuum tube collectors made of glass tubes) achieve the highest level of efficiency.

Fig. 24: Glazed solar thermal collectors on a flat roof (Energie Solaire, top) and integrated in a tilted roof (Buderus, Bosch Thermotechnik GmbH, bottom).

Fields of Application for Stainless Steel

There are rare applications of stainless steel for absorbers as well as the frames.

Requirements of corrosion resistance, high life expectancy, low maintenance and high aesthetic demands suggest the application of stainless steel for absorbers and frames.

2.3.3 Active Solar Façades

General State of the Art

Active solar façades with functions of thermal control have been applied in high-quality buildings, e.g. office buildings and museums. Essential functions of such façades are

- saving heat in the building,
- collecting thermal energy from solar radiation,
- protecting against solar radiation in summer,
- control of daylight,
- exchange of air between indoor and outdoor climate.

Even if they are not normally mentioned, aesthetics and prestige are very important functions of façades in general, including solar façades.

Fig. 25: Thermal solar façade made with absorber for heat exchange from solar radiation to liquid (Energie Solaire, I. Frei).

Fields of Application for Stainless Steel

There are many examples of high-quality stainless steel façades. Active solar systems as mentioned above could be integrated to a greater or lesser extent.

The main condition for application will be the development of façade systems, including all the functions mentioned above and even including → photovoltaic systems (2.4.2).

2.3.4 Solar Stoves

General State of the Art

Solar stoves are used for cooking and for water purification and/or sterilization in developing countries, mainly in hot arid climates with a high level of direct solar radiation.

Simple solar stoves are equipped with good thermal insulation for longer cooking processes and with reflecting lids.

To achieve higher temperature levels for special applications they are often combined with concentrating systems and then have to be tracked following the sun.

Fig. 26: Solar stoves with reflectors for better heat gain (solemyo)

Fields of Application for Stainless Steel

Thanks to its good reflecting properties and high life expectancy, stainless steel is the ideal material for the reflectors.

2.3.5 Concentrating Thermal Systems

<u>General State of the Art</u>

Systems concentrating solar radiation require a high proportion of direct radiation as in hot arid climates and a continuous reorientation of the system in line with the position of the sun. Depending on the degree of concentration and therefore on the temperature in the focus, the most common systems are medium concentrating systems with one-dimensional tracking by parabolic mirrors. In rare cases, systems with two-dimensional tracking are applied.

Fig. 27: Solar thermal power plant with two-dimensional tracked heliostats (top), two-dimensional tracked concentrators (bottom left) and with one-dimensional tracking by parabolic reflectors (bottom right) (Forschungs-Verbund Sonnenenergie)

<u>Fields of Application for Stainless Steel</u>

Solar power plants with parabolic mirrors have been realized in hot arid or semi-arid climates. Corrosion-resistant stainless steel mirrors with support structures made of the same material are a combination of optimum precision and high life expectancy.

2.3.6 Support Structures for Thermal Collectors

General State of the Art

Thermal collectors on flat or pitched roofs or independently of buildings need a weatherproof and corrosion-resistant support structure. Stainless steel can be considered for the replacement of galvanized steel or aluminium.

Fig. 28: Support structure for thermal collectors (Buderus)

Fields of Application for Stainless Steel

The requirements of corrosion resistance and low maintenance suggest the application of stainless steel for frames and profiles as well as for complete support structures and fastenings. This is of special importance to avoid corrosion problems due to the combination of different metals.

2.3.7 Active Solar Cooling Systems

General State of the Art

Cooling systems can be operated by compressors, normally driven by electricity. Alternative systems use absorption or adsorption chillers, driven by heat. Systems with an output of > 20 kW are state of the art, and smaller systems are in the development stage. The heat can be produced by solar collectors. The heat of the same collectors can be used for heating in cold seasons and for cooling in warm seasons. An additional advantage of solar cooling systems is the simultaneity of the solar radiation supply and the cooling demand. So there is no need for heat storage. The coldness may be transported into the rooms by a liquid medium in e.g. cooling ceilings or via the air in an air conditioning system. In tropical and subtropical zones a reasonable market for solar cooling systems is expected because of the electricity-saving potential, especially at times of peak demand.

In the absorption chillers process, ammonia is used as a cooling agent. It is absorbed in water. In the adsorption process water is adsorbed in e.g. silica gel, a solid material. Both processes are closed. The main criterion is the fact that they can be operated with heat from solar collectors.

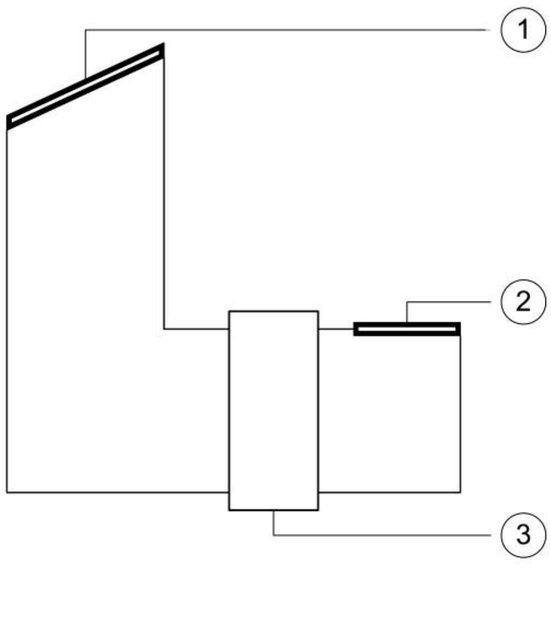


Fig. 29: Active solar cooling system with thermal glazed collector (1), absorption/adsorption cooling device (3) and cooling ceiling or fan (2).

Fields of Application for Stainless Steel

The application of solar cooling systems requires solar collectors providing a medium (adsorption process) to high (absorption process) temperature level. Due to the construction of the collectors, their elements represent fields of application for stainless steel, such as absorber sheets, frames and support structures.

2.4 Stainless Steel in Photovoltaic Systems

2.4.1 Photovoltaic Roof Elements and Systems

General State of the Art

Roofs inclined to the south have the optimal orientation for photovoltaic arrays. This is the reason why most of the building-integrated systems are installed on roofs or integrated into roofs. Roofs of residential buildings are usually covered with tiles or other small elements, whereas most photovoltaic modules have dimensions of about 1 to 2 m².

In these cases, the integration of photovoltaic modules in roofs means employing prefabricated or job-fabricated flashings. Commercial and public buildings, however, usually have roof cladding made from larger units, e.g. metal sheets.

Photovoltaic modules of amorphous silicon can be produced as flexible elements that can be glued onto e.g. metal sheets. This makes it possible to cover an entire roof with the same system, the metal sheets being partly photovoltaic active and partly not, as required. Photovoltaic roofing systems in this form are available with metal sheets and with plastic roof sealing.


Fig. 30: Stainless steel roof element with installation of photovoltaic modules (Rudolf Schmid, left). Photovoltaic roof element on the basis of galvanized steel (Hoesch-Contecna, right).

Fields of Application for Stainless Steel

There are already roofing systems with stainless steel for pitched and flat roofs. So it should be possible to develop stainless steel photovoltaic systems as particularly durable alternatives to other roofing materials.

2.4.2 Photovoltaic Façade Elements and Systems

General State of the Art

When integrated into façades, photovoltaic modules, besides generating electricity, generally assume different functions. One of these is a certain selective degree of shading in transparent building elements. Here modules with a glass reverse side are applied.

For non-transparent sections of façades, flexible modules on metal sheets can be applied with the advantages of more design freedom and lower costs.

Fig. 31: Crystalline photovoltaic balustrade elements (left, Ertex Solar) and crystalline photovoltaic façade elements in metal framework, inside (right, STAWAG).

Fig. 32: Photovoltaic façade elements on the basis of galvanized steel and flexible triple junction photovoltaic modules (Hoesch-Contecna).

Fields of Application for Stainless Steel

As there are already façade systems with stainless steel, it should be possible to develop stainless steel photovoltaic systems as particularly durable, aesthetic and/or prestigious alternatives to other façade materials.

2.4.3 Reverse Side Foil Cover

General State of the Art

Common photovoltaic modules with crystalline solar cells have a reverse cover made from plastic foils (opaque modules) or glass (semi-transparent modules).

Fig. 33: Standard crystalline photo-voltaic module (SCHOTT Solar). The reverse side usually is a plastic foil.

Fields of Application for Stainless Steel

The reverse-side plastic foil could be replaced by a foil of stainless steel to get more stiffness and reduce the risk of damage during transport and mounting. Stainless steel frames and reverse side will improve the weather resistance and durability in use.

2.4.4 Concentrating Photovoltaic Systems

General State of the Art

There are several attempts to lower the system costs of photovoltaic systems by concentrating solar radiation on a small photovoltaic cell with high efficiency. The reasons for the hitherto rare application are the high temperature that causes a decrease in efficiency, and additionally the necessity of a precise orientation adjustment.

Fig. 34: Concentrating device for photovoltaic cells two-dimensionally tracked on metallic support structure (Fraunhofer ISE).

Fields of Application for Stainless Steel

The application of building-independent concentrating photovoltaic systems requires a high-precision support structure and tracking system as well as high corrosion resistance and high life expectancy.

2.4.5 Support Structures for Photovoltaic Modules

General State of the Art

Photovoltaic modules and generators – if not integrated into the building envelope – are mounted on support structures on flat or pitched roofs or on the ground. Those structures have to meet requirements for structural strength and life expectancy. Common materials are galvanized steel, aluminium and even timber.

Fig. 35: Support devices for photovoltaic modules on flat metal roof (Messe München, hwp).

Fields of Application for Stainless Steel

For example, fastening hooks for inclined roofs covered with tiles are sometimes already made of stainless steel.

High life expectancy and low maintenance requirements would be important arguments for stainless steel structures on roofs and on the ground especially in case of combination of different metals.

The minimum life expectancy of a photovoltaic facility is about twenty-five years.

2.4.6 Substrates for Thin Film Photovoltaic Cells

<u>General State of the Art</u>

Thin film photovoltaic cells, e.g. amorphous silicon (a-Si), copper-indium-diselenite (CIS) or Cadmium Telluride (CdTe), need a substrate, usually glass, metal or plastic material.

Modules and cells with glass substrates have the same integration conditions as conventional modules with crystalline silicon cells (→ Fig. 33). Thin film cells and modules can also be based on metal or plastic foils. So they can be flexible and appropriate to be glued onto building elements.

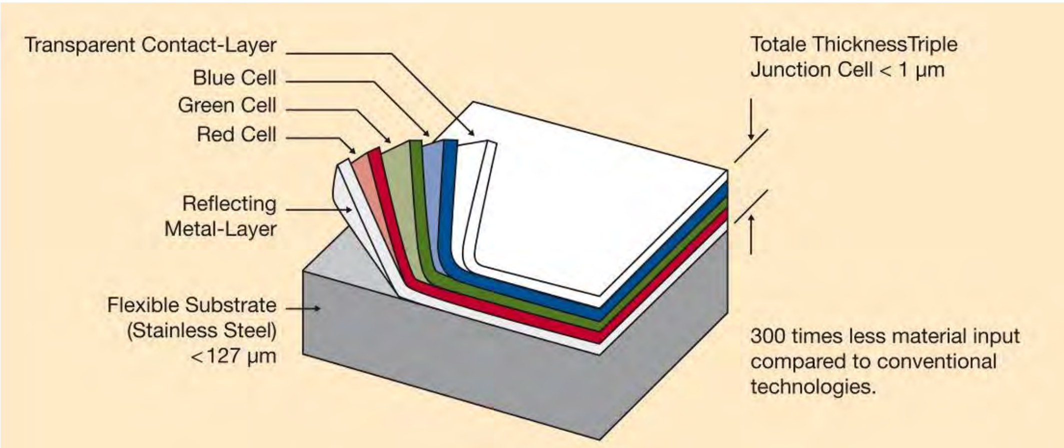


Fig. 36: Cross-section of triple-junction spectrum splitting amorphous silicon alloy solar cell (Uni-Solar).

<u>Fields of Application for Stainless Steel</u>

There are thin film photovoltaic cells with a stainless steel foil as substrate, e.g. the triple junction cells shown in Fig. 36. These flexible modules are suitable for combining with stainless steel roof and façade elements.

An aim of future development could be to coat a stainless steel sheet with the thin film photovoltaic cell in order to form a building element.

2.4.7 Substrates for Organic and Dye Solar Cells

General State of the Art

Efforts to reduce costs in manufacturing and apply photovoltaic systems are leading to new concepts of photovoltaic cells. These are dye-sensitized solar cells (DSC) and organic photovoltaic cells.

Dye-sensitized solar cells offer the possibility of screen printing. They consist of transparent or light-scattering photoactive layers. Potential substrates are glass and polymer foils. The concept allows creative applications with different colours and decorative designs. Research and development activities are focussed on improving their efficiency (at present max. 10 % under laboratory conditions) and on durability.

Organic photovoltaic cells are produced by evaporating organic and carbon molecular structures under vacuum and heat conditions on a substrate. Research and development activities are focussed on improving their efficiency (at present max. 5 % under laboratory conditions) and on durability.

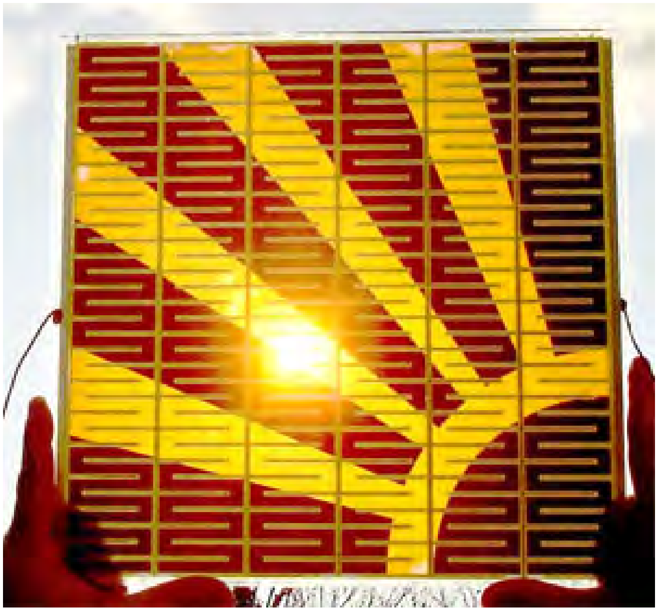


Fig. 37 Dye-sensitized photovoltaic module (Fraunhofer ISE)

Fields of Application for Stainless Steel

The marketability of this technique will probably be achieved in a few years' time. At this relatively early stage of development it seems conceivable to use stainless steel as a substrate or as a building element equipped with dye-sensitized or organic photovoltaic cells.

3. Specific Applications in Different Climates

3.1 Cold and Temperate Climate

These zones, for example northern and central Europe, are characterized by low to moderate average ambient temperatures, a significant difference between summer and winter and a high proportion of diffuse radiation. Room heating and hot water generation are important for the use of solar systems. Photovoltaic generation of electricity becomes important when the aim is to make increasing use of renewable energy.

Systems with special advantages in cold and moderate climates are:

- energy saving systems, e.g. frames for windows and doors (2.1.1), insulated façade and roof elements (2.1.2 and 2.1.3) and vacuum insulation (2.1.4),
- passive solar systems, e.g. shading devices (2.2.2), daylighting systems (2.2.3), greenhouse systems (2.2.4), transparent heat insulation (2.2.6) and phase changing thermal storage materials (2.1.5)
- active thermal systems, e.g. support structures for thermal collectors (2.3.6), high-efficiency solar collector systems (2.3.2) and active solar façades (2.3.3),
- active photovoltaic systems, e.g. support structures for photovoltaic modules (2.4.5), photovoltaic roof and façade elements (2.4.1 and 2.4.2).

3.2 Warm Subtropical Climate

These zones, for example the Mediterranean countries, have high average ambient temperatures, a significant difference between summer and winter and, especially in summer, a high proportion of direct solar radiation. Hot water generation and room heating are important uses of solar systems as well as electric power generation.

Systems with special advantages in warm subtropical climates are:

- passive thermal systems, e.g. thermal storage wall (2.2.1), shading devices (2.2.2) and daylighting systems (2.2.3),
- active thermal systems, e.g. support structures for thermal collectors (2.3.6), low temperature absorber systems (2.3.1), low-tech solar collector systems (2.3.2) and concentrating thermal systems in power plants (2.3.5),
- active photovoltaic systems e.g. support structures for photovoltaic modules (2.4.5), photovoltaic roof and façade elements (2.4.1 and 2.4.2) and photovoltaic modules in power plants.

3.3 Tropical Arid Climate

The tropical arid climate is characterized by the highest proportion of direct solar radiation, high ambient temperatures and generally high temperature differences between day and night.

Systems with special advantages in tropical arid climates are:

- passive thermal systems, especially for compensating room temperature between day and night, e.g. thermal storage walls (2.2.1),
- active thermal systems, e.g. solar furnaces (2.3.4) and concentrating thermal systems, especially in thermal solar power plants (2.3.5),
- active photovoltaic systems, e.g. small solar home systems (2.4.1) and large PV power plants as well as large prestigious solar façade systems of PV (2.4.2) and shading (2.2.2) in office and public functions.

3.4 Tropical Humid Climate

The tropical humid climate is characterized by constant high temperature and a high proportion of diffuse solar radiation and only slight temperature differences between day and night.

Systems with special advantages in tropical humid climates are:

- active photovoltaic systems, e.g. solar home systems for generating electricity for refrigeration and room conditioning (2.4.1 and 2.4.5), as well as prestigious solar façade systems (2.3.3 and 2.4.2).

4. Research and Development

Scenarios for further stages in the development of stainless steel applications in building-integrated and independent solar systems could be

design of elements on a state-of-the-art basis with the chance of quick realization for stainless steel systems, e.g.
support structures for thermal collectors or photovoltaic modules applicable under high corrosion conditions (→2.3.6, 2.4.5),
photovoltaic roof elements with thin film modules (→2.4.1),
reverse side stainless steel foil cover (→2.4.3),
photovoltaic shading devices (→2.2.2, 2.4.2),

development of elements for special applications including tests and prototypes, e.g.
concentrating parabolic mirrors and support structures for solar thermal power plants (→2.3.5),
elements for building integration of thermal and photovoltaic solar systems (→2.4),

basic research on solar elements including later development and design for new applications, e.g.
substrates for thin film photovoltaic cells (→2.4.6),
transparent heat insulation (→2.2.6),
vacuum insulation (→2.1.4),
phase-changing thermal heat storage devices (→2.2.7),
substrates for organic and dye-sensitized solar cells (→2.4.7).

It is evident that design activities can be realized with relatively little effort and expense in a short period of time, but also that, on the other hand, basic research and development will use up more time and resources – but with the chance of being the first supplier of a new system on the market.

It will always be helpful for the introduction of new systems and components to the market to present them together with prominent buildings as demo projects. Additionally an important issue should be to make investigations on the possibilities of integration of solar systems into existing buildings.

5. Conclusions

Possibilities for applying stainless steel can be found in nearly all the solar systems mentioned in this report. But there are clear differences that should form the basis for future decisions. These differences mainly concern the following aspects:

- the estimated quantities of stainless steel that could be applied in the system in question,
- the estimated results of research and development already available for developing alternatives using stainless steel for the system in question,
- the estimated market acceptance for system alternatives on the basis of stainless steel,
- the estimated cost efficiency of stainless steel in the specific system in comparison with other materials in the same application.

Taking this into account, there are some systems that are particularly suitable for the application of stainless steel. In particular, possible combinations with other systems should be taken into consideration on the basis of affinity of materials, elements and systems. With reference to **building integration** these systems are:

- external shading devices in combination with daylighting and photovoltaic façade systems (2.2.2, 2.2.3 and 2.4.2),
- greenhouse systems for residential and non-residential application (2.2.4), combined with solar thermal (2.3.3) and photovoltaic (2.4.2) façade elements,
- solar thermal absorber and collector systems (2.3.1 and 2.3.2) in combination with flashing elements and support structures (2.3.6),
- photovoltaic roof elements and systems (2.4.1),
- photovoltaic façade elements and systems (2.4.2), especially in combination with frames for windows and doors (2.1.1), insulated façade elements (2.1.2), external shading devices (2.2.2), daylighting systems (2.2.3) and active solar thermal façade elements (2.3.3).

In addition to building-integrated systems there are also **systems without building integration** suitable for the application of stainless steel. Concentrating systems for solar thermal power plants (2.3.5) are of great importance in arid and semi-arid climates. Support structures (2.3.6 and 2.4.5) are important for applications which have high life expectancies and are subject to aggressive weather conditions.

Taking the effort and cost required by research and development into consideration, the following recommendations can be made:

- For short term introduction into the market, greenhouse and glazed atrium systems (see above), for example, are recommended, including system design and design tools.
- For a mid-term realization period, photovoltaic façade elements and systems, for example, would require some development activities and system design including design tools for application.
- A great deal of time and effort in basic research would be necessary for e.g. vacuum insulation, transparent heat insulation and phase-changing thermal storage systems. In particular, the development of building elements and system design would be of great importance. The possibility of high-level systems will be combined with a longer period for realization.

Any decisions made should also take account of the fact that the possibilities vary depending on the know-how and significance of enterprises involved and on regional market conditions. Some of the systems can be developed with reasonable cost and effort by a single enterprise, whereas others require a team that includes capacities for basic research, the development and testing of elements, system design and manufacturing. This report has been elaborated to provide the basis for discussion and decision-making with regard to these aspects.

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Buderus, Bosch Thermotechnik GmbH, Wetzlar, Germany	Fig. 24, Fig. 28
Charlet, Melanie	Fig. 19
COLT BOMIN SOLAR, Kleve, Germany	Fig. 15
Energie Solaire SA, Sierre, Switzerland	Fig. 23, Fig. 24, Fig. 25
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ForschungsVerbund Sonnenenergie, PSA/DLR, Berlin, Germany	Fig. 27
Fraunhofer ISE, Fraunhofer Institut für Solare Energiesysteme, Freiburg, Germany	Fig. 34, Fig. 37
Frei, Ivo, Architecte, Lausanne, Switzerland	Fig. 23 Fig. 25
Haver & Boecker Drahtweberei, Oelde, Germany	Fig. 18, Fig. 20
Hoesch-Contecna, Oberhausen, Germany	Fig. 10, Fig. 30, Fig. 32
hwp – hullmann, willkomm & partner, Hamburg, Germany	Fig. 12, Fig. 13, Fig. 19, Fig. 21, Fig. 22, Fig. 29, Fig. 35,
Rudolf Schmid GmbH, Rosenheim, Germany	Fig. 30
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solarnova® GmbH, Wedel, Germany	Fig. 14, Fig. 17
SOLEMYO, Geneve, Switzerland	Fig. 26
STAWAG, Aachen, Germany	Fig. 31
Uni-Solar, United Solar Ovonics, Frankfurt, Germany	Fig. 36
VARIOTEC GmbH & Co. KG, Neumarkt, Germany	Fig. 11
Wacotech GmbH & Co. KG, Bielefeld-Brake, Fachverband Transparente Wärmedämmung e.V., Germany	Fig. 21

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