CZASOPISMO TECHNICZNE A
WYDAWNICTWO POLITECHNIKI KRAKOWSKIEJ

z. 4-A/2007
ISSN 0011-4561
ISSN 1897-6271

NIKOLAUS ZIESKE*

INSTALLATION OF PHOTOVOLTAIC SYSTEMS IN EXISTING BUILDINGS

OGNIWA FOTOWOLTAICZNE W BUDOWIE I BUDYNKACH ISTNIEJĄCYCH

A b s t r a c t

With the aesthetic properties of solar-active surfaces, it is possible to develop a wide range of modern architectural forms. The external appearance of such module is just as fascinating as the silent, clean and environmentally friendly manner in which it operates. Therefore solar facilities should not be seen as purely technological components which are simply installed into buildings, but as a potentially creative architectural element. Integrating photovoltaic installations in the roofs and façades of new buildings poses no serious architectural or technical problem. Integrating photovoltaic installations in the roofs and façades of existing buildings, on the other hand, is more complex. Nevertheless, it is possible to achieve an aesthetically pleasing result, if sufficient care is taken with regard to scale, colour, materials and decoration. Naturally, it is extremely important to choose the right module especially in terms of colour, transparency and surface texture.

Keywords: *solar architecture*, *photovoltaic systems*

S t r e s z c z e n i e

Estetyka powierzchni solarnych pozwala na rozwój różnorodnej, nowoczesnej formy architektonicznej. Urok powierzchni modułów solarnych fascynuje tak samo, jak ciche, czyste, sprzyjające środowisku działanie. Dlatego systemy solarne nie powinny być same w sobie rozumiane jako elementy technologiczne budynku, tylko z całą świadomością stosowane jako elementy architektoniczne.

Integracja PV-systemów z dachem i fasadą nowo powstających budynków jest możliwa zarówno technicznie, jak i twórczo. Instalacja PV-systemów w budynkach już istniejących jest bardziej kompleksowa. Udaje się ją jednak estetycznie zrealizować, biorąc pod uwagę skalę, kolorystykę, materiały oraz elementy dekoracyjne stanu istniejącego. Aby uzyskać zamierzony efekt, należy dokonać odpowiedniego wyboru modułu jako najwidoczniejszego komponentu systemu, szczególnie jego koloru, przezroczystości i struktury powierzchni.

Słowa kluczowe: *architektura słoneczna*, *ogniwa fotowoltaiczne*

*Prof. Nikolaus Zieske, University of Applied Sciences, Gießen-Friedberg.

1. Electricity from sunlight – solar energy/photovoltaic

Photovoltaic – generating electrical power from solar energy − is the only non-thermal way of producing electricity directly. Once it has reached the building, electric current is the simplest and cleanest way of distributing energy. All the energy needed in a building can be provided by electricity. However, electricity, which must be seen as the noblest and most valuable type of energy, is relatively complicated to produce.

1.1. How much energy does the sun provide?

The power of solar radiation when it hits the outer atmosphere of the Earth is, on average, 1367 W/m². This figure is known as the solar constant. As it passes through the atmosphere, the power of the sunlight becomes weaker and, on a clear day, amounts to approximately 1000 W/m². Solar radiation is composed of a direct and a diffuse part. Solar energy plants make use of both direct and diffuse sunlight. If one adds us the energy content of direct and diffuse solar radiation during a period of one year, it is possible to calculate the global result in average kilowatt hours per square meter area and year. Annual solar radiation in Germany amounts to approximately 1000 kWh/m²/year in flat regions. That means that, given an efficiency of 10%, an area of about 40 m² would be sufficient for a 4-persons household with a requirement of about 4000 KWh/year.

1.2. Types of solar cell and solar modules

The classical crystalline silicon solar cell consists of two differently doped silicon layers. If possible, light should not be allowed to reflect off the surface of the cell. An antireflex layer influences the colouring of the solar cells and thus their efficiency. In this connection, dark blue or black cells have been found to perform best.

1.2.1. Monocrystalline

The manufacture of monocrystalline cells involves the following steps: crushed silicon is melted at a temperature of about 1400 °C; cylinder-shaped monocrystals (ingots) are formed, each with a diameter of approximately 15 cm; these are subsequently cut into wafers, each with a thickness of 0,2 to 0,4.

1.2.2. Polycrystalline

For the manufacture of polycrystalline cells, the molten mass is poured into moulds, where it hardens into a rectangular crystal block. During the cooling process, different-sized crystallites develop, with the result that the overall appearance is less uniform despite having the same colouring. This block can also be used for producing wafers.

1.2.3. Thin-layer (semi-transparent modules)

Thin-layer solar cells are made of various basic materials and are extremely thin. In automated processes, single cells are directly applied − without visible conductors − to a substrate, such as glass or metal foil, by the separation of thin layers of aeriform amorphous silicon or other semi-conductor-related materials:

− Copper-indium-dieselenide (CIS),
− Cadmium telluride (CdTe),
− Amorphous silicon (ASi).

The advantages of thin-layer cells, compared to other types of solar cells, include lower production costs, reduced proneness to shading, higher temperature tolerance, better utilisation of the sun's spectrum, almost unlimited range of module formats, transparency of the material, homogenous appearance and greater flexibility in form.

Solar-cell manufacturers coat the wafers and equip them with contacts for energy transfer. In a further step, the individual solar cells are assembled together with the corresponding wiring to make PV modules. The cells are then connected and covered with a glass panel, which is break-proof, weather-resistant and sturdy. Typically, such modules have a performance of 10 to 170 Wp. Depending on the type of cell or module, a solar-power system with a capacity of 1 kWp takes up an area of between 6 and 25 m².

1.3. Planning and basis for construction

1.3.1. Planning

1.3.1.1. Orientation

Various features of the respective building have to be designed with a view to obtaining maximum sunlight and minimum shade. It should be a basic consideration in town-planning that all buildings face south. In Germany, optimal energy yields can be achieved with a roof which is inclined at an angle of about 30° and pointing in a southerly direction. However, a variation in direction of ±10° and/or a variation in inclination of ±5° does not have a significant effect on performance.

1.3.1.2. Shade

It is essential to ensure that the solar-energy system is completely free of shade. Shade prevents the solar module from producing energy. This problem is less serious in the case of thin-layer modules. However, such modules are, in general, less efficient.

1.3.1.3. Rear ventilation

The efficiency of crystalline silicon solar cells increases the cooler they are. Therefore, it is important that the system has functioning rear ventilation.

1.3.2. Energy technology

This text does not deal in depth with dimensioning, technical design, yield estimates or electrical installations. Only the inverter module will be mentioned. It ensures the connection between the solar generator and the alternating current network. Existing buildings are, as a rule, integrated in the local infrastructure, which means that single solutions based on an individual's own feed-in do not make much sense. Furthermore, with the help of network supply and remuneration for the amount of energy produced, house-owners become independent of the need to generate electricity permanently for themselves.

2. Costs/revenue

Since the introduction of the network-supply law (Stromeinspeisegesetz) of 1990 and the follow-up law pertaining to renewable energy (Nachfolgegesetz über Erneuerbare Energien EEG) of 2000 in Germany, energy providers are obliged to accept electricity which has been generated in their area from renewable energy sources − water, wind, sun, biomass − and to reimburse the supplier with a minimum amount as laid down by law. The rate is minimum 51,0 cents/kWh for the electricity which is generated by solar energy in the first 5 years. In this way, the legislator is seeking to make PV modules more attractive as an element of design for both architects and contractors. Facade installations may also provide an image bonus, because they are more obvious to the observer.

3. Areas of application in existing buildings

3.1. Possibilities of assembly

Due to the rapid development on this particular market, architects and planners have a wide range of solar-energy-related products with varying applications at their disposal. In integrated systems, solar modules can be used to replace whole components of the roof and façade or be fitted to the rainproof shell of the building.

3.1.1. Roof

Roofs are ideal for the installation of solar power plants since they constitute a large unbroken surface which is openly exposed to the sun. Flat roofs are especially well-suited for this purpose, because there are generally no hindrances concerning the installation of the modules. There is a fundamental difference between systems which are fitted onto the roof and those which are fitted into the roof. In cases where the unit is to be retrofitted, complete subassemblies are available at a reasonable price, although they may not be as attractive as the integrated system. In-roof systems are more complicated, but aesthetically more pleasing. Actually, the extra costs are not necessary a deterrent if standard modules can be used and if they can be installed at a time when the property is being developed or modernised anyway (e.g. as a water-bearing layer).

3.1.2. Façade

The situation with façades is in some ways comparable to that with roofs. However, due to the presence of windows, balconies, etc., it is considerably more difficult to find large unbroken surfaces. A further problem is inherent in the age of the building and the style of architecture. It is certainly challenging to design a solar energy system for buildings dating back to preindustrial epochs or from the time before the Second World War, since most of them were solid structures coated with plaster or timber-framed. The façades of such buildings are generally too delicate for the large-scale laminar elements of a modern solar--energy installation (e.g. Wilhelminian style). Things are far easier with buildlings which have been erected since the end of the second world war, because they often have a concrete skeleton with facings. During the development and modernization of such buildings, it is indeed possible to supplement the standard functions of the façade (e.g.

insulation, protection against the influence of the weather, acting as a windbreak, soundproofing) with the task of producing electricity. Moreover, this can significantly improve the image of the respective building.

3.2. Design

Solar plants should not only be seen as technical systems, but also as elements which can contribute to, enhance and accentuate architectural design.

3.2.1. Principles of design

One ambitious solution is to consider the existing roofs as homogenous surfaces and to cover them completely with photovoltaic elements. The elements, at least those on the south side, should look like new roofing material and extend down as far as the gableboard, eaves and ridge. It may be necessary to fit dummy elements, which merge in with the general appearance, but do not produce electricity. Sometimes, the size of the module has to be adapted. Another possibility is to define individual surfaces which are complete in themselves and which can be blended into the overall design. An example in this case might be the roof areas of special dormers facing south. As with the roof, it is also advisable with the façade to consider small-scale surfaces as interrelated elements or to enhance existing architectural features. Suitable examples in this case might be the space between the windows, small parapets, balconies or cornices. In general, there are three different approaches regarding design:

1. Opposition − creating an antipol to what already exists by adding one's own independent and con-trasting features, e.g. a solar pergola over a roof terrace as protection against the weather.
2. Dialogue − creating a new interpretation and further development of what already exists.
3. Adaptation − creating a subtle blending of what already exists with new and modern elements. In this way, photovoltaics can also be a form of mimicry which fits unobtrusively into the given structure.

3.2.2. Multifunctionality

It makes good sense to use photovoltaics together with structural components which in themselves usually have other purposes, such as protecting against the influences of the weather, safeguarding privacy or acting as a sunshield. Additional areas where photovoltaics might be installed include loggias, conservatories, car ports, porches and shutters. Sunshields, of course, constitute ideal areas for solar energy systems, since they are generally installed in places where they are needed to keep out the sun, i.e. where solar radiation is strongest. Moreover, it is usually no problem in this case to create optimal rear ventilation. The ideal solutions for sunshields are semi-transparent modules.

3.2.3. Colouring/texture (surface structure)

The development of photovoltaic products has up to now mainly concentrated on improving energy efficiency. More recently, however, more attention has been paid to the importance of design as a marketing factor. Here are some examples.

Colour and pattern

Because of the physics of energy absorption, the range of colours that can be used for solar cells is greatly limited. As a result, crystalline cells are usually blue and amorphous, whereas CIS cells appear black, and CdTe cells have a greenish shimmer. Any variation in the colour of the antireflex layer leads to a reduction in efficiency. The standard tints used for the solar modules are, however, in stark contrast to the more muted shades of older building materials or the natural colours of the environment. One possibility of changing the colour without interfering with the technology of the manufacturing process is to use printing. But this is an extra production step and therefore adds costs.

Ceramic screen process

A four-coloured dot screen is printed on the glass cover of a thin-layer module. If the screen is not thin enough, efficiency will be reduced (possibly by as much as 10−20%). The basic colour of the module is still black or dark green. However, for the observer, the bright, luminous colours seem to create a new tone.

Semi-transparency

Semi-transparent elements open up new possibilities of architectural integration. With this technique, wonderful patterns can be developed, leading to an attractive interplay of light and shade. However, semi-transparency presupposes changes in the manufacturing process. Semi-transparency can be created with the following steps:

– embedding cells a certain distance apart in the module, thus creating gaps;
– direct mechanical intervention in the cell:
    - by laser vaporisation of partial areas,
    - by scoring or milling, e.g. to create a striped pattern or round hole pattern, whereby the width of the stripes is variable and can thus be adapted to architectural requirements,
    - by combining patterns and coloured background.

When using this process, one has to consider the loss of efficiency in any calculations regarding yield and surface.

Surface structure

The smooth, shiny and reflecting surface of the front side of the module often contrasts with the matt, uneven and irregular surfaces of traditional building materials such as brickwork, masonry, plaster or roofing tiles. To reduce this unwanted effect, it is possible to sandblast the surface of the module without loss of yield. Another possibility is to use textured glass as a covering layer. Various favourably priced types of glass are available for this purpose. The advantage of such a method is that no additional intervention in the manufacturing process is necessary.

3.3. Construction

3.3.1. Roof

3.3.1.1. Additive solutions

In the case of older buildings with slanted roofs, the photovoltaic module are frequently fitted on top of the existing roof covering with up stands assembly systems. The advantages of this method are the relatively low costs and, above all, excellent rear ventilation of the module. Up stands systems can also be used on flat roofs.

3.3.1.2. Integrative solutions

Integrative systems can be used in new buildings or when the roof of an old building is being renovated or modernised. Such in-roof installations are somewhat intricate, but aesthetically rewarding. The roof has to be constructed from the beginning in accordance with the standard modules which are available. The solar elements, which themselves are waterproof, can, at the same time, be used as water-bearers. It is important to have good rear ventilation. Other possibilities include solar roofing tiles or solar roofing shingles, which are fitted just like normal tiles. In the case of flat roofs, there are one-layered, multifunctional roof-sealing strips with integrated photovoltaic modules made of flexible thin-layer cells in 3-layer technology.

3.3.2. Façade

Yields from façade installations are significantly lower than is the case with roof installations. However, because they are part of the shell of the building, photovoltaic plants can, in addition to producing electricity, function in terms of protection against bad weather, heat insulation and shielding against the sun. They constitute a valuable part of the façade, which means that they are an important new element in architectural design. Furthermore, they help to give the building and its owner a good image. Solar façades can basically be divided into cold façades, warm façades and double façades.

3.3.2.1. Additive solutions

Cold façades are clam-shell constructions. The outer shell has the function of protecting against bad weather, architectural design and, in this case, energy production. The bearing structure behind it is responsible for the statics of the buidling and heat insulation. Because of the rear ventilation, this construction is very well-suited for the installation of photovoltaic elements. As with the roof, standard modules are fitted to the façade on assembly rails. When mountings are situated in grooves or boreholes the modules are fixed by means of retainer clips, special clamps, rivets or screws. In the case of double façades, an additional transparent glass shell is put in front of the original intact façade in order to improve the climate of the building together with the soundproofing. The outer shell is ideal for the integration of photovoltaics, because it consists of just one layer and provides excellent rear ventilation.

3.3.2.2. Integrative solutions

Warm façades have, at the same time, a statically function, regulate heat insulation and provide protection from bad weather. Warm façades have no rear ventilation. In many cases mullions and transoms constructions with a dry glazing system are used.

R e f e r e n c e s

[1] H e r m a n n s d ö r f e r I., *Solardesign*, *Photovoltaik für Altbau*, *Stadtraum und Landschaft*, Berlin 2005.
[2] H a s e l h u h n R., *Photovoltaik, Gebäude liefern Strom*, Karlsruhe 2006.
[3] A l t h a u s D., *Fibel zum ökologischen Bauen*, Berlin 2000.
[4] http://www.solar-integration.de.
[5] http://www.pvaccept.de.
[6] http://www.alwitra.de.
[7] http://www.systaic.de.
[8] http://www.wirsol.de.
[9] http://www.centrosolarglas.de.
[10] http://www.ertex-solar.at.
[11] http://www.solarnova.de.