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Research Project

Adaptation and Further Development of Photovoltaic Thin-Film Technology for Back-Ventilated Rain-screen Façades of Composite Panels Partially Clad with Tinted Glass

PV-VH-Fassaden

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1 Aim of the research assignment

This research project deals with the adaptation and further development of thin-film photovoltaic (PV) technology for composite cladding panels used in back-ventilated, rain-screen façades. The goal of this research was to improve the acceptance and distribution of PV modules in architecture. The resulting new PV modules, applied to standard façade elements, can be covered with tinted glass.

The ventilated rain-screen façade is a highly effective system relative to economic efficiency, ecology, durability and comfort when separately constructing the functions of thermal insulation and weather protection. Such a system is used both in new and refurbished buildings. The combination of this type of façade system with additional heat insulation methods offers significant potential for energy savings. The thermal protection standards for low-energy buildings can be met by choosing the appropriate thickness of the insulating material. Panels made of fibre cements, ceramics, brick, metal or other materials are available as cladding, as well as support panels for applications of plaster, glass, ceramic or metal. Clamps on the back-side of the support panels allow for hidden connections and a visually homogeneous façade surface. These elements combine modern envelope construction with the demands of high-quality façade refurbishments.

Figure 1 Ventilated rain-screen façade with iridescent glass composite panels (back-side connected) at the GEWOGE, LUWOGE BASF service centre in Ludwigshafen, Germany. Architects: Allmann Sattler Wappner.

Rain-screen façades are ideal for the integration of PV modules given their rear ventilation properties. The ventilation space enables the erection of simple electrical connections using standard junction boxes in non-visible areas on the back-side of the modules. The wiring can be routed throughout the heat insulation layer. Elements are easily accessible and can be replaced individually for purposes of maintenance and repair.

Architecturally, the conventional attachment of PV systems to buildings can often generate aesthetically displeasing results. New innovative materials and techniques are needed to facilitate the widespread use of building integrated PV façades further. Planners, building owners and regulatory agencies are rather reluctant to accept PV technology in architecture. This is due to the limited product range and expressive design of conventional PV modules of crystalline silicon cells in addition to the relatively high costs and lack of know-how by architects and designers. On the other hand, PV planners seem to avoid the use of integrated solutions because of their association with considerable technical and regulatory efforts compared to common PV installations which need not meet the constructive requirements of the façade.

PV elements integrated into the façade of buildings do not only produce energy but also fulfil important architectural and constructive functions. PV modules as new and innovative building products offer new opportunities in architectural design as a result of their favourable material properties such as laminated glass products and possible combinations with other building materials. Many fundamental questions in terms of their use and implementation, however, still remain unanswered. Very little experience and expertise currently exist concerning the long-term behaviour of PV elements in modern glass façade systems. Furthermore, these issues are very important with regard to the economic efficiency, energy savings and sustainability of these façades. Technical and construction design details need to be clarified, as well as the status of building regulations.

The thin-film technology offers new and advanced production and design options compared to conventional silicon solar cells. A standard module of thin-film cells has a dark gray and homogeneous surface. The EU sponsored BIPV-CIS[1] project involving three of the project partners resulted in copper indium diselenide (CIS) thin-film modules for building integrated PV (BIPV) allowing a wide spectrum of surface modifications including flexibility of colour schemes. These newly developed modules can better be adapted to the built environment given the variety of their textures and structures while simulataneously providing for ideal conditions for the combination of PV modules and energy-saving building techniques such as ventilated rain-screen façade systems. The composite panels to be developed under this project comprise of a foam glass support panel with an optionally coloured thin-film PV module. These panels help to broaden the repertoire of creative expression available; provide robust and durable weather protection; and produce electricity.

For years, architecture has been experiencing a great interest and high demand of fully glazed façades which is evidenced by numerous national and international projects. Colour, as a design element, plays an important role in the language of modern architecture. The architecture of Bruno Taut is a good example. Coloured glass façades result in a high-quality of architectural and urban development.

The goal of this research project was to provide basic conditions for the integration of PV elements in ventilated claddings of coloured glass façades. PV thin-film technology was prototypically adapted and modified during the development process. This procedure supported the research of products within the industry and fostered the subsequent market launch. Successful results from this product's initial development have the potential to spur additional development of innovative construction materials and techniques. This will increase the capacity of innovation within the construction industry, as well as strengthen the international competitiveness of the PV- and façade business.

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[1] EU project BIPV-CIS – Improved Building Integration of PV by using Thin-Film Modules in CIS Technology

2 Processing of the research task

These objectives have been accomplished by an interdisciplinary team of partners from science, industry and practice. This research team consisted of the Institute of Building Construction, which served as the project manager, and the Institute of Construction Management both of the Technische Universität Dresden; the Centre for Solar Energy and Hydrogen Research (ZSW); and two industry partners StoVerotec GmbH and Würth Solar GmbH & Co. KG. This project consortium analyzed the basic techniques of PV thin-film technology to modify these for prototype production of PV rain-screen façades starting with market research and patents of ventilated rain-screen façade technology and photovoltaic façades. Criteria and requirements have been derived and technical feasibility and relevant building regulations were examined.

An analysis of the BIPV-CIS modules showed that these modules are not suitable to be attached to composite cladding panels in back-ventilated rain-screen façades. Therefore, an additional industry partner was consulted – DELO Industrie Klebstoffe (industrial adhesives) – to conduct experiments of adhesive capabilities of sample modules in their laboratory. Experimental rigs for the production and practical testing of various prototypes of PV modules were assembled. The most important questions to be addressed were: how to adapt the appearance of the façade cladding; how to predict and ensure the desired colour; how to couple the PV modules electrically; and how to analyse or determine the chemical and physical requirements of appropriate materials for the adhesion of composite layers.

Façade element prototypes were developed in order to evaluate practical applications of PV thin-film technology in construction products, as well as the structure’s service life and long-term behaviour of façade elements. The project partners decided to extend the component and material tests to include fire tests during the project period since fire behaviour of a new product is an important aspect which should be determined.

Life cycle analyses with the goal of proving the advantages and potential of PV thin-film technology were conducted. Exemplary simulations with a specialised tool developed specifically for this project provided universal results regarding the economic validity of the new products depending on various influencing factors. At the same time, huge benefits and potential concerning energy and CO_2 savings in buildings were shown.

Project work was concluded and recommendations were made for practice which will be published to foster further knowledge and technology transfer. The knowledge gap between building owners, architects and planners and researchers must be closed in order to establish the acceptance of PV elements as equivalent construction products with the additional value of generating electricity. Therefore, an enhanced knowledge transfer and easy-to-access professional information is required. Projects results have been presented on relevant trade fairs and conferences in the fields of construction and photovoltaics, as well as frequently published both during and after the project period.

3 Summary of results

An essential achievement of this project was the creation of a prototype composite clad panel with an applied PV thin-film module using CIS solar cells. The invisible fixing components on the back side of the panel do not need any punctual or linear clamp fixings typical of glass panes. Instead, the resulting product is a visually homogeneous façade surface with no limitations for energy production. Additional innovation is apparent in the variety of possible colours and surface designs available.

3.1 Basic evaluation

Important criteria for the practical use of these new elements are given by architecture, building regulations, building methods and management, as well as physical and electrical aspects. Colour and its effects play different roles in urban planning. The choice of colour can influence the orientation, aesthetics, mood and readability. Colour is versatile; it permits the accentuation of components and emphasizes particular views. Many façades gain depth only by their colour since at northern latitudes the sun light alone may not be strong enough to express the 3-dimensional form of a building. The use of colour can help buildings and, hence, the urban space to be more dynamic and multidimensional. Coloured façade elements can also evoke different day and night effects.

In the near future, PV elements will not be regulated construction elements when considering the variety of construction methods and the lack of sufficient building regulations even for conventional glass construction. The technical rules for laminated glass structures do not apply to the composite PV façade cladding. In the past it has been shown that the complex approval procedures and the additional time and cost expenditures act as a barrier to the use of the cost-intensive photovoltaic technology as part of the façades. For this reason, short- and medium-term product approval appears to be the best solution for a successful market launch. The project examined appropriate testing methods for a national technical approval (allgemeine bauaufsichtliche Zulassung – abZ). Component and material tests on small PV module samples have shown that the glass panes coated with solar cells are able to maintain the required strength of float glass. The adhesion of the module laminate complies with the maximum expected loads including sufficient safety. Thus, the PV modules are in principle suitable for the use in the façade elements.

Similarly, photovoltaic elements are not characterised and defined in terms of fire protection. Depending on the individual application, façade elements must meet certain requirements. A classification without testing (fire tests) is not allowed for PV elements because of a lack of experimental experience. In this project, fire tests on prototypes of the PV modules conducted by an external laboratory served as an initial basis for future classification. The results suggested that the laminated PV glasses delivered by Würth did not reach the same German class B1 as the support panels of StoVerotec, and, consequently, the composite elements cannot be expected to meet the B1 classification, as well.

In addition, stability, suitability and durability of the façade must be guaranteed by the choice of suitable materials, the assembly, the dimensioning and the design of all components of the façade construction. The common mechanical load test of solar modules in accordance with IEC 61646 applies to load corresponding to 2400 Pa optionally increased to 5400 Pa. Higher loads or requirements corresponding to DIN 1055 part 4 can be met using thicker cover-glass. Product development must also allow for construction methods which influence the construction progress from planning and mounting to utilization and disposal.

The cladding consists of a PV module laminated on a support panel. Parameters such as the relevant temperature range and the linear expansion coefficient of the connected elements are of interest for the build-up, as well as the U-value of the support panel, in order to estimate the expected temperature increase of the module and its effect on the electric parameters.

3.2 Further development of coloured thin-film PV modules

The coloured modules developed in the research project BIPV-CIS needed some improvement regarding the planned adhesive bonding without securing the cover glass mechanically. The tinted cover-glass is optically decoupled from the layers below in order to intensify the colour impression of the existing modules. Yet, a decoupling of the border area is not possible since this is the physical connection of the laminate, colour at the edge will always differ from the remaining area. Another difficulty is to ensure stability when the entire weight of the cover-glass must be transmitted via the edge bond. Thus, this design was rejected by the project partners and other solutions were developed.

Initially, a distributed force transmission was examined in the application of adhesives in a finely structured manner – for example in line or dot formation. Dyed adhesives could also create colour impressions even with clear cover-glasses. Experiments involving a well-proven adhesive on an industrial scale failed, however, due to the shrink behaviour of the adhesive associated with the large formats of the façade element. After 500 hours of humidity-heat testing, the bond collapsed. There were leaks, humidity and corrosion inside the module.

As an alternative, cover-glasses coated with zinc oxide on one half were applied as an additional layer with a different refractive index. It was possible to laminate the entire surface of these colour glasses avoiding the disadvantage of unfavourable force transmission. A homogeneous colour impression, however, would require an additional printing step in the border, uncoated area. The intensity of the optical effect was dependent on the point of view and the lighting conditions. Consequently, the project partners did not continue to pursue this version

The fourth solution analyzed was dichroitic glasses whose colour changes with the angle from which the glass is viewed and the solar irradiance spectrum. Sample modules with these new architectural glasses in blue/gold, green/gold, blue/green and green – the dual colour specification refers to variable angles of view – resulted in a very intensive colour effect. The border area plays a minor role in this case. The contours still show through very weakly but likely will disappear with blackened edges. A change in the viewing angle leads to a change in colour but does not affect the intensity. A transmission of about 50 % was determined related to the spectral response of CIS solar cells. Semi-transparent mirrored glass resulted in higher transmission values of about 72 % and more visible border areas in turn. For larger quantities, the glass manufacturer announced the possibility of adapting the reflection of the glass to increase the CIS-specific light transmission. The unknown compatibility for outdoor use is a problem to yet to be solved in addition to the insufficient transmission. Therefore, dichroitic glasses are an attractive option for future development which requires further investigation exceeding the scope of this project.

Figure 2 Prototypes of coloured thin-film PV modules produced for façade cladding elements using inorganic coated cover-glasses.

Inorganic coated cover-glasses promised the best results in terms of visual qualities. The benchmark determined for their further development as cladding prototypes for PV façades was a maximum efficiency loss of 30 % compared to conventional black CIS modules. Current measurements on coloured glasses and prototypes in green, blue, red and yellow, each in three to four tones of intensity suggest performance losses from 4 to 10 % (blue), 9 to 20 % (red and yellow) and 11 to 25 % (green). The more intense the colour, the greater was the measured loss.

3.3 Prototype of a ventilated façade cladding with coloured thin-film PV modules

A façade mock-up was constructed according to the production guidelines of the ventilated rain-screen façade system StoVerotec Glas for demonstration and testing purposes. The assembly of the PV modules and the cladding elements should both be possible in portrait and landscape format in order to satisfy architectural claims. The position of the module junction box did not cause any difficulties.

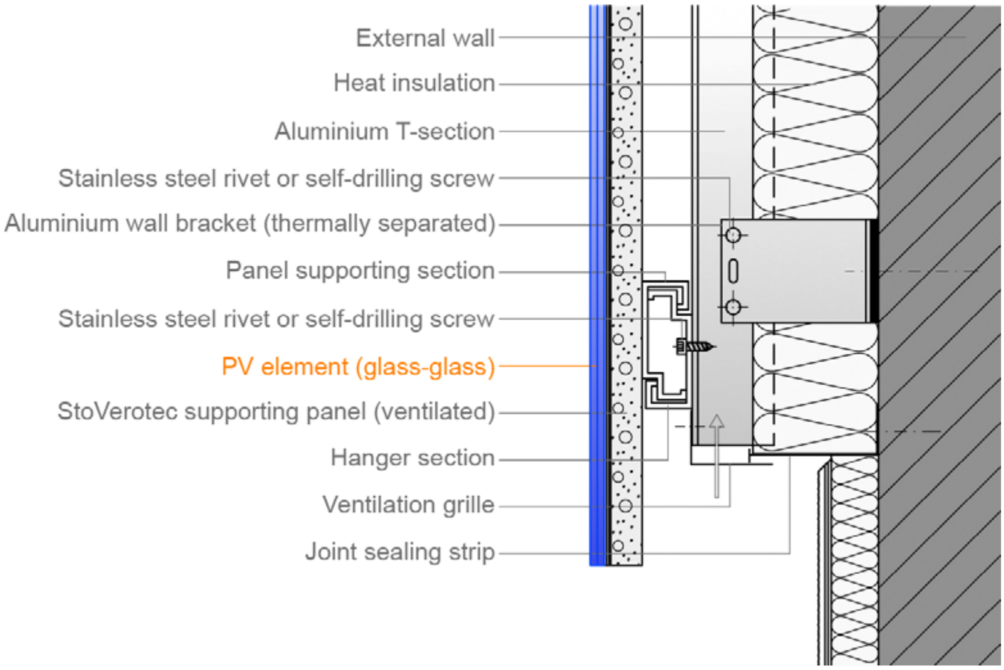

Figure 3 Cross-sectional view of the façade construction (principle)

The experimental investigations on the prototypes included, in particular, the temperature and long-term behaviour. An increase in cell temperature reduces the power output by around -0.45 %/K with CIS modules. For CIS modules bonded on foam glass plates and installed vertically, the ZSW assumed a temperature increase of 5 to 6 K in comparison to free standing CIS modules and a maximum operating temperature of around 75 °C in central Europe. Consequently, it is appropriate to adopt the temperature limits of -20 °C to +80 °C as given in DIN 18516 for claddings for external walls. This is still within the test range of IEC 61646 with temperatures from -40 °C to +85 °C. This qualification standard includes, among other things, durability tests. PV modules approved by these tests are considered to be very reliable and durable.

In the environmental simulation system of Sto AG, a test wall with four coloured PV modules was artificially weathered according to the guideline for European technical approval of thermal insulation composite systems with rendering (ETAG 004). The tests included a heat-rain cycle and a heat-cold cycle lasting 25 days. The element did not suffer any damage, detachments, cracks or other defects, but the PV modules showed opacities a few centimetres below the upper edge (2 to 3 cm²) behind the cover-glass. It should be clarified whether this is due to constructive reasons or accumulated moisture.

Figure 4 Aged PV-element; left: Front with optical opacities of the composite film at the upper edge; right: Back-side with junction boxes and aluminium substructure

3.4 Life Cycle Analyses

Life cycle analyses provided universal results regarding the economic validity behind the use of the novel façade elements under a number of varied influencing factors. A simulation tool specially developed for this project helped to contrast the revenue and expenditures of the life cycle costs for over 20 years of operation between a reference glass clad rain-screen façade and the PV rain screen façade. This exemplary analysis included different scenarios with variable PV module colours, façade orientations, system sizes and technical parameters at six representative German locations. Similarly, subsidy schemes and different financing conditions were incorporated.

The expenses included all investment and follow-up costs. The manufacturing costs of the PV façade system consisted of the PV module costs from the manufacturer; the construction costs; and the electrical system technology. The difference between reference construction costs and those of the PV rain-screen façade researched was about 300 €/m². Planning costs were estimated to be double due to the complexity of planning and coordination of the PV rain-screen façade. The annual operating costs for insurance, electrical service, operational control, reserves for repairs, maintenance and service amounted to 1% of the respective investment costs with an inflation rate of 1%.

Revenues of the PV façade came from the compensation paid for the solar electricity generated and fed into the grid under the German Renewable Energy Sources Act (EEG). The selected feed-in tariff refers to a PV system commissioned in 2008 and included a bonus of 5.0 cents/kWh granted for façade integration. The payment is prescribed from the date of commission for a period of 20 calendar years, as well as for the year of commission. Input parameters, such as the local solar irradiation, shading loss as a percentage, typical values for the system quality (performance ratio PR) and output power losses due to the colour of PV modules are variable in the simulation tool to determine the expected annual energy yield. Annual power degradation due to ageing of 0.3 % was assessed from the 3^{rd} year for CIS modules.

PV façades deviating up to +/- 30°from south orientation proved economically viable at all locations examined within the operating period of 20 years using colour modules with up to 20 % power loss. At high-sunshine locations in Southern Germany, southeast and southwest façades with +/- 60° south deviation also provided positive results. At particularly good locations, even pure east and west orientations with 10 % power reduced colour modules were economical when the conditions were favourable. The economical viability remains to be analyzed on a case by case basis, however, given the large number of possible scenarios. In some cases, economic viability of the system cannot be achieved. Losses due to shading, for example, were not considered in the sample calculations. Increasing the system size, on the other hand, improves the profitability of south oriented PV façades. Generally, prospects are good that PV systems can be used to generate electricity beyond the considered period of 20 years. This assumption favours the use of the PV façade. Nevertheless, as a conclusion the ventilated PV rain-screen façade currently is only cost-effective for high-quality façades of representative buildings.

Subsequent heat insulation methods for façades allow energy savings up to 40 % given the current building stock in Germany. In combination with integrated PV modules, this additional energy activation of the building envelope yields renewable electricity in the amount of around 700 kWh per kW_p output power and is associated with a CO_2 reduction of approximately 620 kg CO_2/kW_p. With CIS thin-film modules, this corresponds to an annual solar yield of about 55 to 80 kWh/m² avoiding CO_2 emissions of 50 to 70 kg per m² a year, depending on the colour modulation.

3.5 Application potential

The benefits of the PV cladding system were visualized using the example of a rain-screen façade built with integrated PV modules at a residential high-rise building in Berlin. While the actually applied polycrystalline modules with their typical frost pattern and raster expressively influence the appearance, the new thin-film modules create a homogeneous façade area without visible margins. With conventional PV modules, modulations in colour and surface were as yet only possible by selecting certain solar cell types and back cover types (glass or film) and by combining the modules with other cladding elements. In the new system, this can be implemented using the same solar cell technology. In addition, the support panel can be finished with a variety of surfaces such as glass, plaster, natural stone or ceramic while permitting a variety of possible combinations in the same façade system. The architect is now free to design the PV area as an accent for the rest of the façade or to integrate it into the general view of the façade. To this end, manufacturers and planners have to work out constructive details and standardize the systems – for example, an optimal cable routing in the façade element. Furthermore, fixing techniques need to be developed based on the existing façade system. These should be adapted to the parameters of the photovoltaic cladding elements and should not evoke peculiar changes on the construction site.

Practice has shown that the façade bonus of 5 cents/kWh in the EEG feed-in compensation currently is insufficient taking into account the additional costs and lower yields compared with standard PV installations on roofs and open spaces. Hence, the future development of the costs will be the decisive factor for market success. Since the CIS technology has an enormous development potential in production technologies, additional cost reductions can be assumed for the coming years.

The lack of long-term experiences and studies for the use of thin-film modules in façades calls to question the long-term behaviour relative to the aesthetic, constructive and electrical aspects of these new composite elements. Further research and educational work is necessary so as not to compromise the interest in innovation against the investment risks of the owner and liability risks of the planners and implementing companies.

The successful manufacturing of prototypes and proven potential for practical applications have resulted from the work of the PV-VH-Fassaden project. Both industry partners involved in this undertaking declared a substantial interest in an immediate transfer of the results of this basic but practical research work into the development of marketable products. A wide dissemination of new findings on PV thin-film technology and opportunities provided by the integration of CIS modules into back-ventilated, rain-screen façades will be ensured by additional publications and integration into subsequent research and teaching. Thus, a quick implementation of these results into practice is ensured.