ARCHITECTURAL INTEGRATION OF PHOTOVOLTAIC SYSTEMS - THE NEW PREMISES OF FRAUNHOFER ISE

Hermann Laukamp, Sebastian Herkel, Klaus Kiefer, Karsten Voss, Sören Andersen [1)]
Fraunhofer-Institut für Solare Energiesysteme ISE, Heidenhofstr. 2, D-79110 Freiburg
Tel: +49 761 4588 5275, Fax: +49 761 4588 9000, email: helau@ise.fhg.de
1) Dissing+Weitling, Postboks 1970, DK 1414 Kopenhagn

ABSTRACT: The Fraunhofer Society has just realised a new building for its institute Fraunhofer ISE. This building is a good example for energy efficient building design using a holistic planning approach. Among other features the building comprises five photovoltaic systems with a total rated power of 20 kWp. These PV systems demonstrate various approaches of building integration. Photovoltaic modules are used as glazing elements in a facade with heat insulated glazing, in a glazed shed roof, where they reduce solar gains in summer, as cladding elements for ventilation equipment on flat roofs and as cladding elements in the cold facade of an office building. The planning team placed great value on the balance between building aspects and maximum electricity generation. Design of custom modules as well as string wiring was done to minimise the effects of partial shading.
Keywords: Building Integration - 1: Shading - 2: Custom Module - 3

1. GENERAL PROJECT BACKGROUND

Fraunhofer ISE is a research institute working on solar energy (www.ise.fhg.de). For many years its facilities were spread over some six buildings in an area of about 0,5 km². The new building brings these parts together and provides a modern research facility with up-to-date energy efficiency features and a healthy and pleasant atmosphere for its employees.

The building site is located on the northern edge of the central area of the City of Freiburg. It is a narrow lot extending in north/south direction.

Gross floor area of the building is 13 000 m², net use area is 6 500 m². One third of the latter area is used for offices, the remaining two thirds comprise laboratories and workshops. Cost of building construction and building services equipment is about 11 million EURO (1700 EURO/m²).
The building was completed in July 2001.

1.1 Building concept

The building combines a high-quality working environment and a high functionality with a low energy consumption and a high design quality.

Most of the building complex is three storeys high (Fig. 1). It consists of three parallel building wings connected by an access tract, which is adjacent to a technical prototype laboratory. The comb structure and the interior zoning were chosen to achieve south-orientated offices for maximum daylighting.

Thermal insulation, solar control, lighting and ventilation technology have been designed for a minimal energy demand. For the offices energy demand is planned to stay 35 % below the current building code requirements.

2 SOLAR DESIGN FEATURES

The comb-like ground-plan and the separation between the wings were chosen on the basis of minimal shading, good daylighting conditions, comfortable summer temperatures, passive cooling, passive use of solar energy and, last but not least, a pronounced horizontal transparency for pleasant indoor atmosphere.

Figure 1: The new premises seen from south-east, bevor mounting of the PV system at the spamdrel of the south facade (photo: Guido Kirsch).

The main entrance foyer is dominated by an atrium with a saw-toothed roof and integrated PV modules.

External venetian blinds with a light-redirecting function provide solar energy flux control.

An underground heat exchanger cools or pre-heats the inlet air for ventilation of the entrance block. The building mass is cooled down in summer by active nocturnal ventilation.

The chosen concept has proven its value in similar applications and is appropriate to the pronounced north/south orientation of the lot. The three building wings are oriented east/west and are widely separated to allow daylighting. The offices, which are not air-conditioned, are located on the sunny side, while the air-conditioned laboratories are on the shady side. The flat roofs of the wings have been designed to function as outdoor test areas. The wing structure and the internal distribution of zones combine passive use of solar energy for heating in winter (sun low in the sky) with low over-heating loads in summer (sun high in the sky). A central access tract extends more than 130 m in the north/south direction and protects the inner courtyards and the wing facades from the summer afternoon sun. An entrance block at the southern end of the access tract houses the administration and central services. The technical prototype laboratory, clean room and workshops adjoin the access tract to the west and reduce heat gain into offices from westerly sun.

2. THE PV SYSTEMS

The PV generators demonstrate different aspects of building integration (see figure 2 and table II):

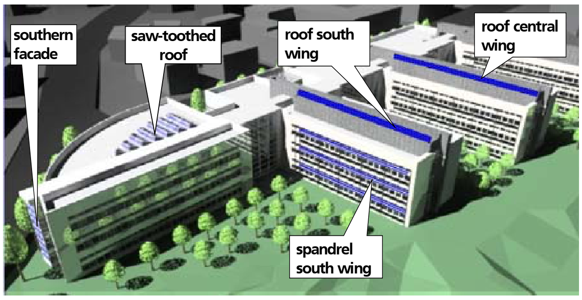


Figure 2: Computer animation of the new building with its five photovoltaic systems .

Table I: Position and rated power of the PV systems

Position	Power [kWp]	mounting
Facade access tract	2.4	heat insulating glazing
Saw-toothed roof	5.0	heat insulating glazing
Spandrel south wing	3.9	vertical + inclined spandrel
Roof southern wing	4.5	flat roof
Roof central wing	4.8	flat roof

In the southern facade and the saw-toothed roof, the solar cells are encapsulated within double glazing. They reduce the heat gain to the building and support the efforts to dispense largely with conventional air conditioning. The generator on the facade of the southern wing will demonstrate the application of photovoltaic modules as spandrel elements in vertical and tilted configurations. The generators on the roofs of the southern and central wings serve as cladding for the ventilation shafts behind them.

In the context of an energy efficient building the PV systems produce on an annual basis as much electrical power as needed to light the offices, about 15 MWh.

Commissioning of the systems took place in fall 2001. In the following sections details for the subsystems are given.

3.1 Roof of wings

The PV arrays on the roofs of the southern and central wings serve as cladding for the ventilation shafts behind them. They employ standard modules in a standard mounting structure. These modules replace an initially planned sheet metal wall. The cost for the support structure is completely recovered from the saved sheet metal wall.

This idea was developed during the construction process after the north wing had been nearly completed.. It had not been included in the original »call for tender«. Therefore, only the later parts of the building, central and south wing, benefit from this idea.

Support Structure

Concrete elements above the structural members of the building structure bear galvanised steel frames. These are inclined at 30 °. On these frames a mounting structure Type »AluTec« is screwed which holds the modules of Type ASE - 100-GT-FT in place (figure 3, 4).

This module was chosen, because it employs the same cells (ASE EFG 100x100) as are used in the access tract facade. Of course, it also fits well into the available geometric boundaries.

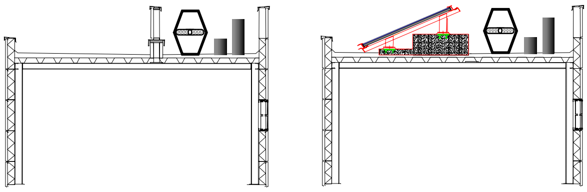


Figure 3: Sectional view of the originally planned sheet metal wall on the flat roofs of the wings and its replacement by a PV array.

Figure 4: The PV generator on the flat roof of building C. At the left side test modules can be seen, which will be replaced in November 2001 (photo: Guido Kirsch).

45 Modules on the south wing and 48 modules on the center wing are wired into 3 strings each and connected to a 5 kW inverter each.

3.2 Facade of Access Tract

This PV generator serves as an »eye-catcher« for visitors coming from downtown. It employs EFG cells with their rather homogeneous appearance in a large area module. The cells reduce the heat gain of the south facing glass facade.

Figure 5: View on the facade of the access tract (photo: Guido Kirsch)

The cells were chosen as a compromise between the homogeneous, dark appearance of mono-crystalline cells and the lower cost of poly-crystalline cells. Additionally, the manufacturer, RWE Solar, claims a lower embodied energy compared to other wafer technologies.

The facade is subject to shading from nearby trees and a building on the other side of the street. Therefor we designed the module in close co-operation with the manufacturer, Flabeg Solar International, as well as the string wiring to minimise shading losses. Due to the architects demands of uneven numbers of columns and rows, a special asymmetric wiring was developed to utilise all cells. A vertical partition was necessary to limit the number of cells per bypass diode.

Each module consists of two horizontal submodules (fig 6), thus reducing the area simultaneously affected by partial shading Three submodules are connected to form one string of 260 V Voc (fig. 7). The lower and the upper part of the facade form two independent subsystems with one inverter (SMA, 1100 W) each.

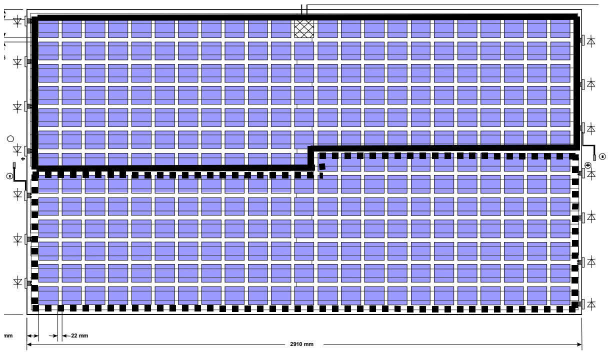


Figure 6: Drawing of the facade module, 299 cells, 400 Wp, 2 x (87 V, 3 A). The electrically independent submodules are marked for better distinction. Uneven numbers of rows and columns demanded an asymmetrical internal wiring. The cell in the upper row, center column is a sensor cell for irradiance measurements.

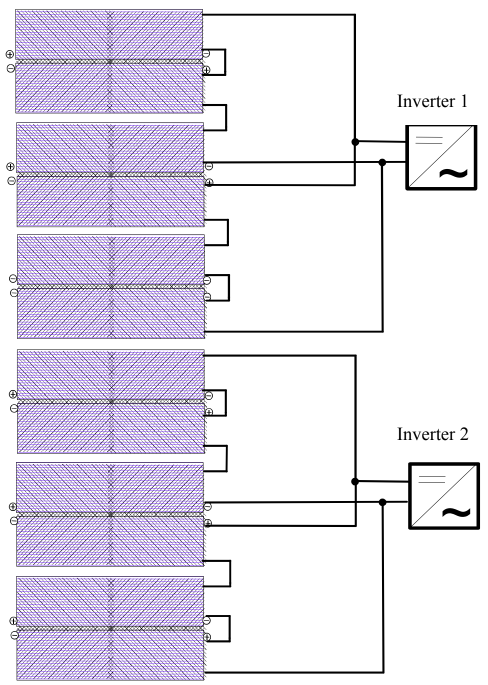
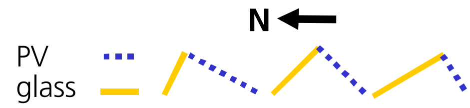


Figure 7: Wiring and position of strings in the access tract facade.

3.3 Saw-toothed Roof of Atrium

The saw-toothed roof over the atrium shall serve as an example of how we developed the construction: Good daylighting conditions are essential for the use and the aesthetic effect of an atrium (fig. 13). On the other hand, enormous overheating would arise in summer, if transparency is high and there are no shading elements. We carried out simulations for the indoor thermal and daylighting conditions to balance both aspects in combination with the electric energy yield of the photovoltaic system.

Fig. 8 illustrates the optimisation of the saw-toothed roof geometry as part of the building concept.



electric power	+	0	-
daylighting	-	0	+
indoor temperature	+	0	-

+ = favourable, - = unfavourable, 0 = neutral

Figure 8: The slope of the photovoltaic generators on the saw-toothed roof is adapted to the energy concept of the building. Electricity generation, daylighting and reduction of heat gains to the atrium in summer were taken into account when optimising the design.

After optimising the geometry of the PV generator the design of the electrical circuits including the PV module was optimised to take into account the partial shading by the southern sheds.

Figure 9 shows the shading situation for the rear rows of the saw-toothed roof. The lower parts of the modules are shaded at low angles of the sun. To minimise shading losses modules were electrically split in three submodules following a suggestion by the module manufacturer, St. Gobain Glass Solar (fig. 10). The upper submodule comprises 6 rows of cells, while the lower one comprises 3 rows of cells. Thus, a fine resolution of insolation utilisation is achieved. The irradiation exposure of the upper submodule is similar to that of a regular flat roof installation.

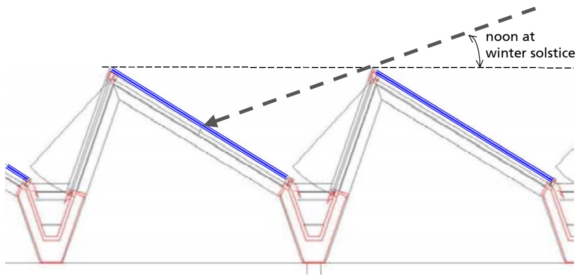


Figure 9: Shading of sheds by southern sheds.

The lower submodules are connected to form one string each (370 V, 4.3 A), the upper module with their twice as high voltage, are connected into two strings (fig. 12.). All strings are wired onto one inverter (Solwex plus, 4 kW is planned, but not yet delivered, temporarily 2 inverters Solwex 20270 E are employed). We expect low mismatch losses from the different irradiance conditions [1].

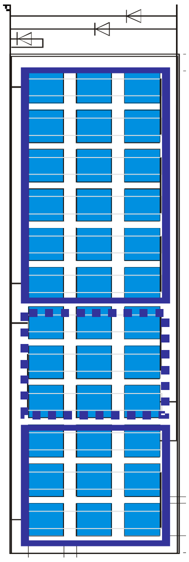


Figure 10: Design of shed roof module with 3 electrically separate submodules (marked by boxes).

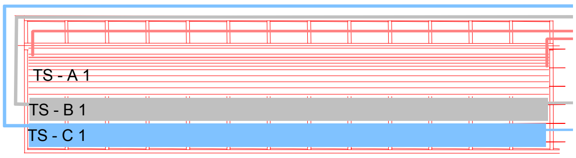


Figure 11: Section of string wiring of the shed array. Submodules are wired horizontally to form strings with identical irradiance conditions.

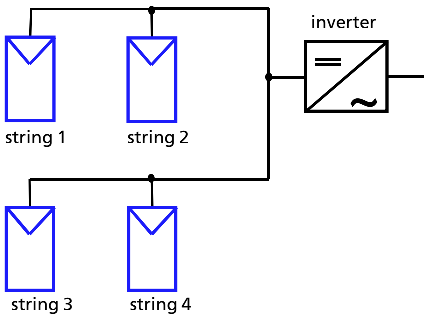


Figure 12: Block diagram of shed array. All strings are wired in parallel onto one inverter.

Figure 13: View into the atrium with its curved wall. The PV cells in the roof create a vivid and ever changing impact on the impression of the atrium (photo: Guido Kirsch).

3.4. Spandrel of South Wing
The appearance of the facade is shown in figure 14.

Figure 14: A view on the facade of the south wing

3.4.1 Module design
The design of Modules for the south facade comprises the innovative »point XS« bracket.
This bracket holds a glass pane through an anchor in a tapped blind hole at the rear side. See figure 15. This means that the module surface is totally smooth. Figure 16 shows a close-photo illustrating this quality.

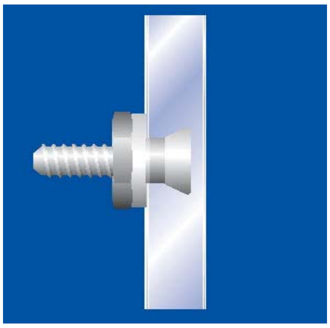


Figure 15: schematic function of the point XS bracket

Figure 16: view on the lower pair of modules with no visible mounting member.

3.4.2 Electrical layout of the facade system

The string layout is a compromise between effort and mimising shading losses.

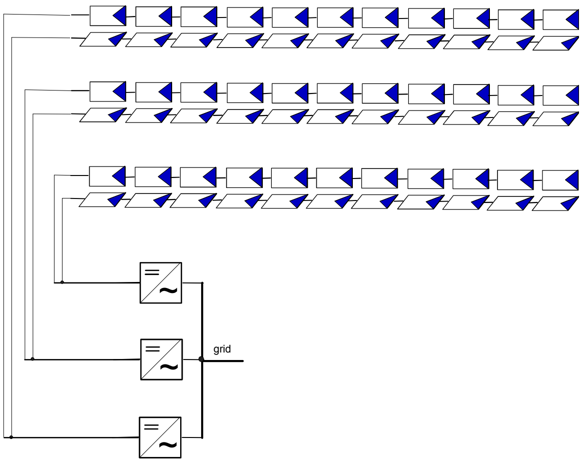


Figure 17: The modules of the same orientation are connected in series and the two strings of one floor are connected to one inverter.

4. THE BUILDINGS ENERGY BALANCE

The photovoltaic systems, with an annual yield of around 15 MWh, will meet about the entire demand for office lighting in the new building. Electricity for lighting is planned at 7.7 kWh/(m²a). For 2000 m² office area this amounts to 15 400 kWh annually.

Fig. 18 illustrates this relation from the perspective of the primary energy. It lists primary energy demands for a conventional new office building in Germany and for Fraunhofer ISE´s new buildings. The loads included are those to be planned beforehand, occupant specific loads are not considered.

Assuming a conversion factor for primary energy to electric power of 0.33 the PV systems will contribute a significant amount of the offices primary energy consumption despite their moderate size.

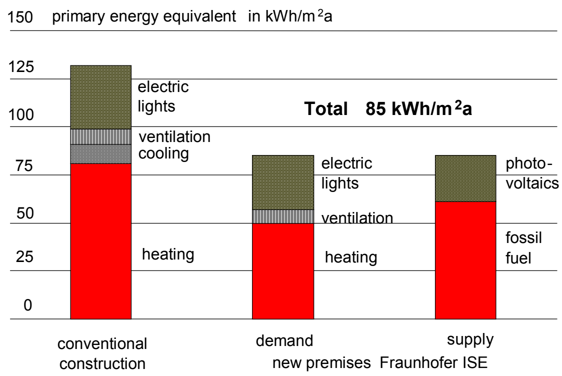


Figure 18: Energy consumption and supply of the new building (center and right column) in relation to the energy consumption of a conventionally planned German office building (left column) from the perspective of the primary energy.

5 . CONCLUSIONS

True integration of Photovoltaics into buildings demands a holistic design approach. It then offers new opportunities for aesthetically attractive solutions to daylighting and overheating prevention. As part of a well designed energy concept PV can contribute a significant amount of the offices primary energy consumption.

A careful design of the electrical systems minimises the effect of unavoidable shading.

ACKNOWLEDGEMENT

We gratefully acknowledge the financial support from the Commission of the European Union in the frame of the »TEAPUB« project.

REFERENCES

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