Fire protection requirements and solutions for the implementation of BIPV on a high-rise residential building in Frankfurt/Germany

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Abstract

Especially for high-rise buildings with their limited roof areas, the activation of the façade with photovoltaics is an important opportunity to improve the energy efficiency of these buildings. With respect to a residential high rise building in Frankfurt, Germany, the research project PV-HoWoSan has been investigating the most important issues for installing photovoltaics in the façade from the point of view of the building owner: statics, fire protection, secure distribution of the generated electricity, Life-cycle assessment and economic efficiency. A major task in order to install the system at the building has been to go through the approval process. PV modules are classified according to an adapted US standard being different to the European standardization system. However, since PV modules usually contain polymer, a classification as non-flammable is not possible within EN 13501. Thus, the investigations within PV-HoWoSan focused especially on the aspect of fire protection. Therefore, a new façade system based on stainless steel material and several fire protection features has been designed. In order to get the required authority approvals, a system burning test was carried out at an official test facility. The paper deals with the experience of the design and approval process.

Keywords: PV façade system, High-rise buildings, system burning tests, PV fire classification

1. Introduction

According to Diefenbach et al., the majority of high-rise residential buildings in Germany and Europe has been built in the period 1985-1978 and are now in a state to be retrofitted. In the context of upcoming renovation measures, the activation of the building envelope with photovoltaics (PV) in combination with thermal insulation offers the opportunity to generate electricity locally in such buildings and to give them a modern and future-oriented design. Often, supposedly high investment costs and uncertainties in the planning process (fire protection, building law, building physics, statics) prevent the use of PV façades.

To overcome these obstacles, the research project "PV-HoWoSan: Development and demonstration of a cost-reduced, industrially produced PV façade system for the renovation of multi-storey residential high-rises buildings", funded by the German Federal Ministry for Economic Affairs and Energy BMWi started November 2017. The research project set itself the goal of using an actual high-rise residential building to investigate the most important issues from the point of view of the housing association - statics, fire protection, secure distribution of the generated electricity, LCA and economic efficiency - to go through the approval process and to install the system on the building. In order to develop an economical and permit-capable BIPV façade system, additional experts have been integrated into the research project.

2. The Demo Building

Fig. 1 shows the demonstration building before renovation. The high-rise residential building of ABG Holding Frankfurt, the biggest local housing company in Frankfurt, built in 1976, has 102 residential units on 16 floors, a height of approx. 47 m and a total floor space of approx. 7,500 m². The existing façade consists of concrete sandwich elements that have a polystyrene core as internal insulation. For the renovation of the façade, the use of a composite thermal insulation system was planned, in which 2 PV strips with a total area of 120 m² were intended

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to be additionally installed on the southern building side. As a high-rise building, the building is classified for approval purposes according to the German “Musterbauordnung” as a special building in building class 5 (GK 5). With respect to this, the Hessian Building Code (HBO), the Administrative Regulation on Technical Building Regulations (H-VV TB) and the Hessian High-Rise Building Guideline (H-HHR-2012) had to be considered. The central fire protection requirement of GK5 is that exterior walls must consist only of non-combustible building materials. In accordance with the high-rise building directive, this requirement also applies to the exterior wall cladding (insulation and facades) of high-rise buildings. The planned use of the PV elements from the project partner SUNOVATION, which are classified as "flame-retardant" (B1), and the necessary electrical cabling represented a deviation from the building regulations (in this case, the special building regulation H-HHR) due to the lack of a generally valid building classification approval for use on a high-rise building.

Fig. 1: Left: View of the façade of the demonstration building in Frankfurt foreseen for the installation of two strips PV. Right: CAD-Model visualizing the planned PV-strips (ABG)

3. Fire protection requirements and design approach

Immediately at the kick-off meeting of the PV-HoWoSan project, it became clear that the fire at the Grenfell Tower in London in June 2017 would also have an impact on the PV-HoWoSan project. Initial discussions with the Frankfurt building inspectorate and the responsible fire protection expert led to the expectation that the design requirements for ensuring fire protection would be higher than assumed at the time of the project application.

Right from the start, the Frankfurt building inspectorate considered the aluminum substructure material commonly used for PV systems to be inadequate in terms of fire protection, so that it was necessary to switch to (stainless) steel. Furthermore, additional design measures were required to prevent the spread of fire. These referred, for example, to integrate cables in special fire protection ducts, the floor-by-floor partitioning of fire compartments by means of specially developed fire bars or to measures for the thermal separation of the PV façade from the concrete sandwich elements (in particular to the combustible insulation of the sandwich elements) of the existing façade.

In a further coordination meeting with the building inspectorate and the Frankfurt Fire Department, the performance of a fire test at a accredited testing and certification center for fire protection was required as a prerequisite for the issuance of an individual approval (ZIE). At the same time, planning for the refurbishment of the Mainfeld 7 high-rise building resulted in a short time slot for the installation of a PV façade by the client, ABG, which effectively reversed the planned course of the project. According to the project plan, the knowledge gained from the design, assembly and installation of the test façade to be built at Fraunhofer IEE was intended to be incorporated into the demo project. As a consequence, it was decided to contact various testing institutes as soon as possible. With MFPA-Leipzig, a test institute could be identified at which it was possible to carry out a fire test in May 2018. With this date, it seemed possible to align the necessary building applications and installation work of the PV façade with the construction schedule of ABG for the renovation of the Mainfeld 7 high-rise building. Therefore, it was decided to start with the development of the novel PV façade system designed by the Richard-Grün-Institut (RGI) for the demo façade and not to wait for the developments on the test façade at Fraunhofer IEE. Due to the short lead time until the fire test, the essential requirements of the building inspectorate and fire department were adopted 1-to-1 in the creation of the fire test model.

The facade system chosen was the suspended pilaster strip approach of the Richard Grün Institute, which promised prefabrication of the facade and rapid on-site assembly. Fig. 2 illustrates the structural design, which consists of horizontal transoms and vertical pilaster strips. The pilaster strips hold the PV modules statically via a suspension system and accommodate the vertical cabling by being designed as a closed channel. Due to the uncertainty about the load-bearing capacity of the existing curtain wall, it was decided to implement the load transfer using the roof. By doing this, the entire structure suspends from the parapet of the high-rise building via the pilaster strips. The horizontal transoms have been designed as closed fire ledgers which are responsible for the residual load-bearing capacity as well as the absorption of the wind loads through the integrated facade anchors.

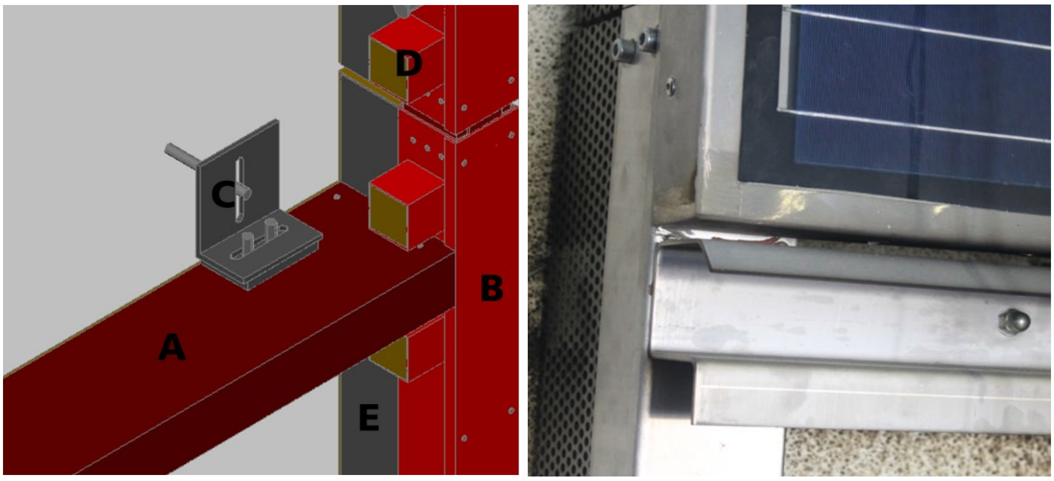

Fig. 2: Left: Structural design of the façade system (A: horizontal fire bar filled with mineral wool, B: vertical pilaster strip, C: façade anchors with slotted holes, D: cable outlets, E: perforated plate reinforcement for horizontal rear ventilation) (RGI). Right: Suspended PV module above the fire bar that extends into the plane of the PV modules.

Fig. 3 illustrates how the fire test was carried out at MFPA Leipzig GmbH. Due to the unavailability of a hall for large-scale fire tests, a full-scale fire test simulating a room fire was carried out in coordination with the Frankfurt Building Inspectorate and in accordance with DIN 4102:20:2017-10 (Fire behavior of building materials and components - Part 20: Supplementary verification for the assessment of the fire behavior of exterior wall claddings). Due to the compromise regarding the test facility, the actual test and thus assessment duration was extended from the required 20 minutes to 30 minutes. The evaluation factors for the fire test were:

- *No enlargement of the primary fire (gas burner) due to the PV design*
- *Effectiveness of fire bars to prevent fire spreading across floors*
- *No independent further burning of the PV construction after the primary fire was distinguished*
- *No dripping of burning components of the construction. Only individual drops of cable insulation can be tolerated*
- *No falling down of construction parts, except for shattered glass*
- *Assessment of smoke development*
- *Assessment of the overall structure under fire exposure*
- *Evaluation of the temperature development behind the External Thermal Insulation Composite System on the surface of the raw test stand (surface of masonry) in order to predict the expected temperature*

development of the facing layer / polystyrene insulation.

- *Proof of the effectiveness of the fire protection bricks installed in the pilaster strips.*

Fig. 3: Carrying out a fire test at MFPA Leipzig. Left: Before the start. Middle: During the test. Right: After distinguishing the primary burning flame

The fire test showed that the essential requirements for fire behavior have been fulfilled by the developed design. Apart from a slight burning of the flamed PV module, the associated low smoke development and the bursting of only small glass surfaces in the area of the primary flame, the PV module stops to burn shortly after the primary flame was extinguished. Thus, it could be shown that the developed construction behaves approximately like a non-combustible system despite consisting of combustible components. Following this, the use in the planned high-rise building renovation appeared to be approvable.

Due to the increased fire protection requirements, which specifically demanded the use of stainless steel instead of aluminum, as well as detailed design adjustments to the RGI basic concept, a significant cost increase for the demo façade was to be expected compared to the original assumption at the time of the project application. Therefore, it was decided that only one PV strip would be realized due to the limited funding volume.

4. First construction phase: insulation measure and facade anchors

On the basis of the fire successful test carried out in May 2018, the application for constructional permit for the statically relevant fastening points for setting the anchors, as well as the roof retaining points was then submitted in October 2018. The planned fixing points of the PV façade construction, based on the fire test, especially the façade anchors with thermal separation via two non-combustible calcium silicate plates (Fig. 4, left), were described in the application. By notification in December 2018, this building application for the installation of the attachment points for a PV strip was approved, so that the planning and implementation of the necessary work could be pursued. This included, for example, the development of a possibility for strain relief of the cabling within the pilaster strip (comp. Fig. 4, right)

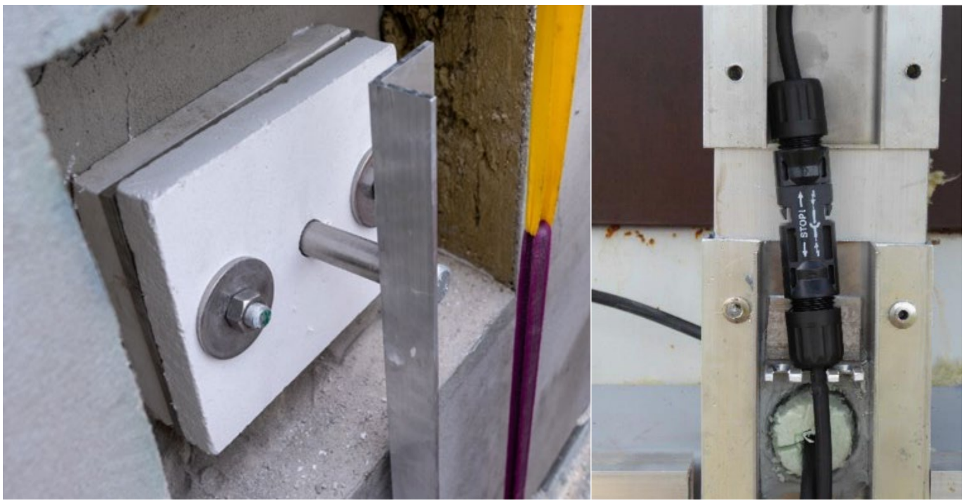

Fig. 4: Left: Facade anchors with thermal separation via calcium-silicate plates (Stark Ingenieure). Right: Strain relief within the pilaster strips

An additional core drilling in the area of the anchors and the replacement of the EPS in the area of the core drilling by mineral wool within the facing shell were to be dispensed when installing the PV facade anchors due to costs and structural reasons. Since this represented a deviation from the fire test carried out at the MFPA in Leipzig, an additional thermal simulation of the anchor situation was carried out. Based on these simulations, the building application was adapted and the execution was approved by the building supervisory authority in November 2019. With the installation of the facade anchors to accommodate the PV facade, the energy refurbishment of the building "Im Mainfeld 7" was completed in May 2019, as shown in Fig. 5. By using these fixed points, almost any facade design could be implemented later on, taking into account the static boundary conditions.

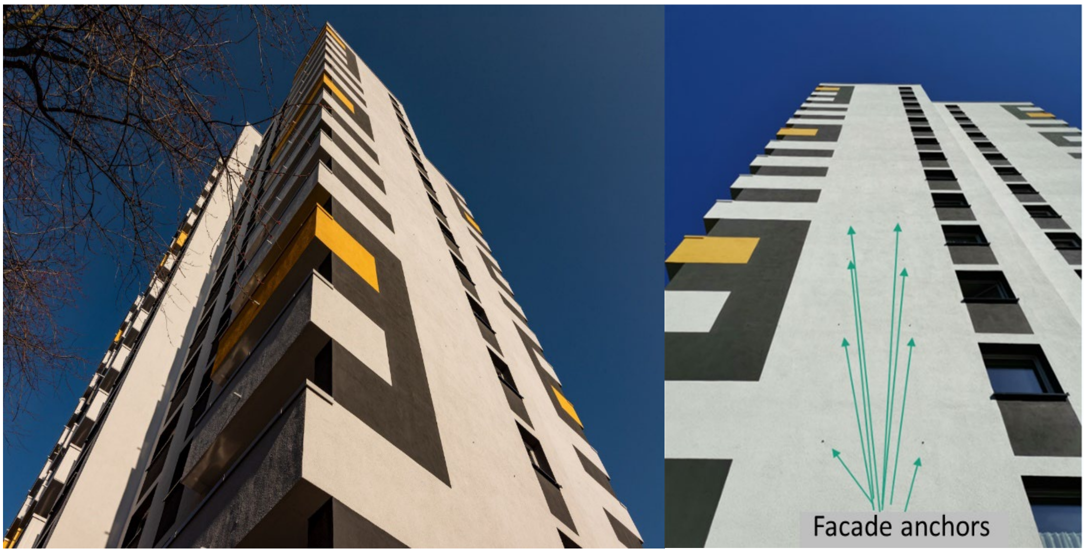

Fig. 5: Demo facade with facade anchors after renovation (ABG).

For the implementation of the second construction phase - the installation of the PV façade structure a decision about responsibilities had to be taken. Due to warranty aspects that could not be fulfilled by the research consortium, an external contractor was planned to be assigned for the installation of the façade. For this purpose, intensive discussions took place with external companies regarding interfaces and responsibilities. However, a bid submitted by a large façade company in March 2020, together with the costs incurred anyway for e.g. PV modules, inverters, implementation planning, fire protection and structural analysis reports, building applications, ZIE, significantly exceeded the originally estimated costs despite the reduction to only one PV-strip. The reasons for the high costs include:

- *High fire protection requirements--> Stainless steel as material, fire bar, bulkheading*

- *Newly developed type of construction, which includes specific elements especially for fire protection reasons → No use of standard profiles*
- *No experience with newly developed system and lack of implementation planning → Risk surcharge*
- *The installation concept, for which the scaffold was no longer available, via access cages and/or industrial climbers*
- *Cross-trade construction → Coordination effort between electrical and facade construction with regard to planning and execution*
- *Existing building → Prefabrication difficult, tolerance*
- *Warranty coverage → High replacement costs in case of damage*
- *Relatively small PV area leads to high kW_{peak} costs*
- *Uncertainties about load transfer of floor slabs → Suspension system*
- *High-rise building → Static requirements, wind loads (static, especially in case of fire), working at height, time required for installation*

5. Further developments at the Fraunhofer IEE test stand

To overcome some of these aspects, the development of a test façade was pursued in parallel. The test façade was to be set up at the Fraunhofer IEE test stand and was planned to be investigated by measurement. Specific approaches were the development of prefabrication potentials, the assembly options, and the optimization of rear ventilation to increase the PV performance, especially in the case of full-surface occupancy of the facade with PV modules.

For this purpose and to support the construction of the façade, a 3-D model of the planned PV installation was developed. The implementation of the test façade is based on the construction principle of the frames and façade construction parts developed for the demonstration building in Frankfurt, whereby the façade approach was selected so that different module sizes can be integrated. As with the demonstration building in Frankfurt, the façade system was suspended from the roof, with additional anchoring in the floor slabs. Furthermore, the central fire protection requirements from Frankfurt were adopted. Significant extensions of the original approach are:

- *Due to the elemented construction method, arbitrarily designed facades with windows, doors, porches, etc. can be served*
- *All perimeter building endings were developed and integrated (floor, roof and side finishes, as well as building corners).*
- *Two energy processing concepts were implemented in the facade: string inverter and module inverter*
- *Line installations can be made in vertical and horizontal way*
- *The assembly and installation work clearly demonstrated the optimization potential of the system.*

Fig. 6 illustrates the assembly process (left), in which a wire rope hoist attached to the roof was used to mount the modules as well as the finished structure (right) facing south-east on the right-hand side and south-west on the left-hand side. The development of the test façade and the test setup have shown that the pilaster strip suspension system further developed in the project can be used to realize a PV façade as a curtain-type rear-ventilated façade with all the required fire protection elements. At the same time, however, it was also shown that a lack of experience with a new system approach as well as manufacturing tolerances can greatly complicate and thus delay the construction and assembly process.

Fig. 6: Left: Test facade during assembly (left) and after finalization (right).

On the basis of the experience gained at the test stand, discussions were held with other façade manufacturers, with whom, however, it was still not possible to achieve a significant cost reduction. In some cases, a bid was not submitted due to technical issues (again, the warranty aspects). Since the building owner cannot assume the additional costs arising in the current situation and the costs are not yet in a justifiable ratio to the electricity yield, the implementation of the developed PV façade cannot be pursued at the demonstration building at the present time, despite the façade anchors already installed.

6. Conclusions

The research project PV-HoWoSan on which this experience report is based, has shown that the implementation of BIPV on high-rise buildings faces great challenges. However, the possibility of developing suitable solutions and of obtaining approval for the construction of a photovoltaic façade designed was demonstrated using an intensive dialog with the responsible approval authorities. The central boundary conditions and possibilities with regard to the approval process are:

- *The use of photovoltaics on a high-rise building always represents a deviation from the respective building code.*
- *In the building class for special constructions, no time limits for the finalization of the approval process are specified by the authorities, which may have a significant impact on the construction process and may represent a risk difficult to be considered.*
- *In close coordination with the building inspectorate and, if necessary, the fire department, ways can be identified so that a building component consisting in part of flame-retardant materials behaves like a non-combustible building component/system*
- *For the design of such systems, the exact analysis of the present building situation is necessary. Important aspects here are:*
    - *Building height*
    - *Access for the fire department*
    - *Hazard situation of the facade where PV is to be installed:*
        - *Arrangement of windows, distance to windows and openings*
        - *If applicable, accessible spaces below the facade*

    - *Fire alarm system and/or extinguishing system available*
    - *Structure of the existing facade: combustible materials installed*
    - *Type of PV modules: Glass-glass or glass-foil modules*
- *Fire tests, both Single Burning Item (SBI) and large-scale fire tests can show important information regarding the fire behavior of products or new system approaches*
- *Existing buildings often have uncertainties regarding the load-bearing capacity of e.g. facing shells or also regarding the exact position of floor slabs. Alternative fastening options such as the roof suspension developed in the project offer promising possibilities to ensure stability even for high-rise buildings*

However, the project has further shown that standardized systems are not available for the implementation of PV on buildings with high fire safety requirements, such as those from building class 5. Significant deviations from standardized designs, however, can result in significant additional costs and are often difficult to implement economically without additional funding. This affects all phases of the implementation of such projects, from preliminary and detailed design, through installation and commissioning, to the warranty period. Here, it is important to have a coordinated and experienced interdisciplinary team in which the interfaces and responsibilities are clearly defined, e.g. by a general contractor. In addition, a close connection to the approval authorities need to be ensured. The PV-HoWoSan project has shown that legally reliable and generalizable statements on new technology approaches can only be obtained to a limited extent from both the approval authorities and the specialist planners.

Furthermore, façade-integrated photovoltaics generally have lower yields compared to roof systems due to their less favourable orientation, which is why economic viability cannot be achieved through electricity feed-in alone. However, the electrical yield of façade-integrated systems is better suited to the use of electricity in the building compared to roof integrated systems. Thus, since contract models for direct use of electricity by tenants are becoming increasingly popular in multi-storey residential buildings, a high rate of owner-use significantly improves economic viability. This is additionally supported if a high-quality façade, e.g. a ventilated façade or a curtain wall, is to be realized with a high-quality appearance even without photovoltaics. In this case, costly substructures do not have to be financed by the electricity yield alone.

The same applies to the question of whether Building Integrated PV (BIPV) is to be attached to new or to existing buildings. With regard to statics and a high degree of prefabrication, integration in existing buildings can lead to great uncertainties, which are usually not be faced in new buildings. The same applies to the issue of fire protection. In buildings classified as special-purpose buildings, high fire protection requirements must be met in new buildings anyway. Hereby, fire alarm systems and extinguishing systems, which can be for example extended to extinguish fire in the facade, are usually available as well as access options for the fire department and sufficiently dimensioned escape routes. All this can facilitate the argumentation of deviations from the building code in the fire protection concept.

In summary, the PV-HoWoSan research project has shown important boundary conditions and obstacles for the implementation of BIPV on special buildings like high-rise buildings. In particular, even if the actual implementation on the demo building was not realized due to cost reasons, a path for planning, approval and implementation could be shown. Such a path could be followed in case of significantly more favourable boundary conditions at alternative buildings.

7. Acknowledgments

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