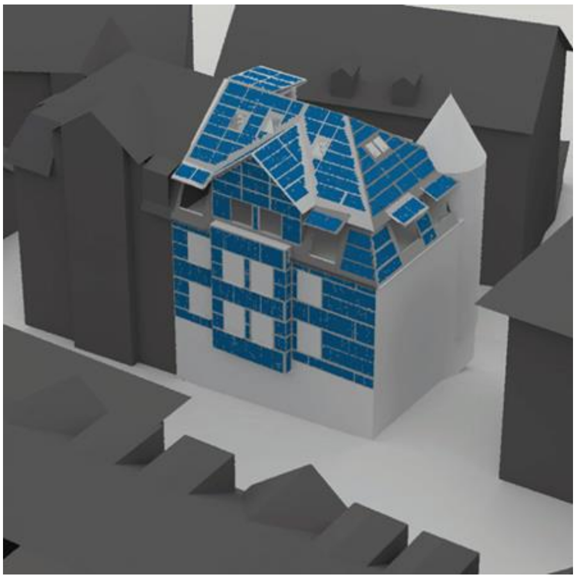
Implementation of BIPV into building simulation



This document represents a demonstrator in WP1:
Façade design & building simulation

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Fluid Flow Glazing can be combined with building-integrated photovoltaics (BIPV) for net-zero energy buildings. This report presents the method that was developed in order to integrate BIPV into building simulations. It presents the results and how useful they can be for future buildings, combining the InDeWaG technologies with BIPV.

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1 Content of Deliverable

The content of this deliverable is the description of a method with which building-integrated photovoltaics (BIPV) can be included into building simulation. This is important because BIPV is a very good option for buildings, which use the Fluid Flow Glazing (FFG) to make the building with its technical building plant a net-zero energy building (nZEB).

2 Results and Discussion

In general, a three-dimensional building model is necessary in order to implement BIPV into a building simulation. This section discusses the challenges and the method, which was developed to address these challenges to provide an accurate calculation of the BIPV contributions to nZEB with FFG and Radiant Interior Walls (RIW). It is important to keep in mind that building performance simulation needs to decouple as many simulations as possible to reach acceptable computing times. Therefore, PV simulations are normally performed separate from the simulation of the nZEB with its FFG and both separate from the detailed calculation of the technical building plant. Finally, the results of all calculations are collected for the life cycle environmental analysis (LCA) and life cycle cost calculation.

As BIPV systems are often a part of a ZEB, a detailed understanding and simulation of such BIPV systems is necessary. The final output of such a BIPV simulation is the time-dependent electrical yield, which can then be used in other building simulation tools. The challenge for BIPV simulation is the fact that each project/ building has its own characteristics. While for standard PV-applications simple simulation tools can be used, the situation for BIPV is very often much more complex: Neighbouring buildings or the building itself cause partial shading of the BIPV modules, often there are different module orientations and module sizes. All these lead to more complex module interconnections and complex inverter requirements that can only be understood with a detailed simulation. The following approach describes such a detailed BIPV simulation, which is also necessary to predict the yield of a BIPV system correctly.

Starting from a 3D building model containing the geometry and materials of the building itself and of the surroundings (buildings, trees, landscape, everything that can cause shadows), a step-wise simulation chain has been developed to calculate the output of a BIPV system. Figure 1 depicts this simulation chain. To describe a BIPV system correctly, all quantities have to be calculated in time steps of typically 5 or 10 min. In the following, the five steps are described briefly:

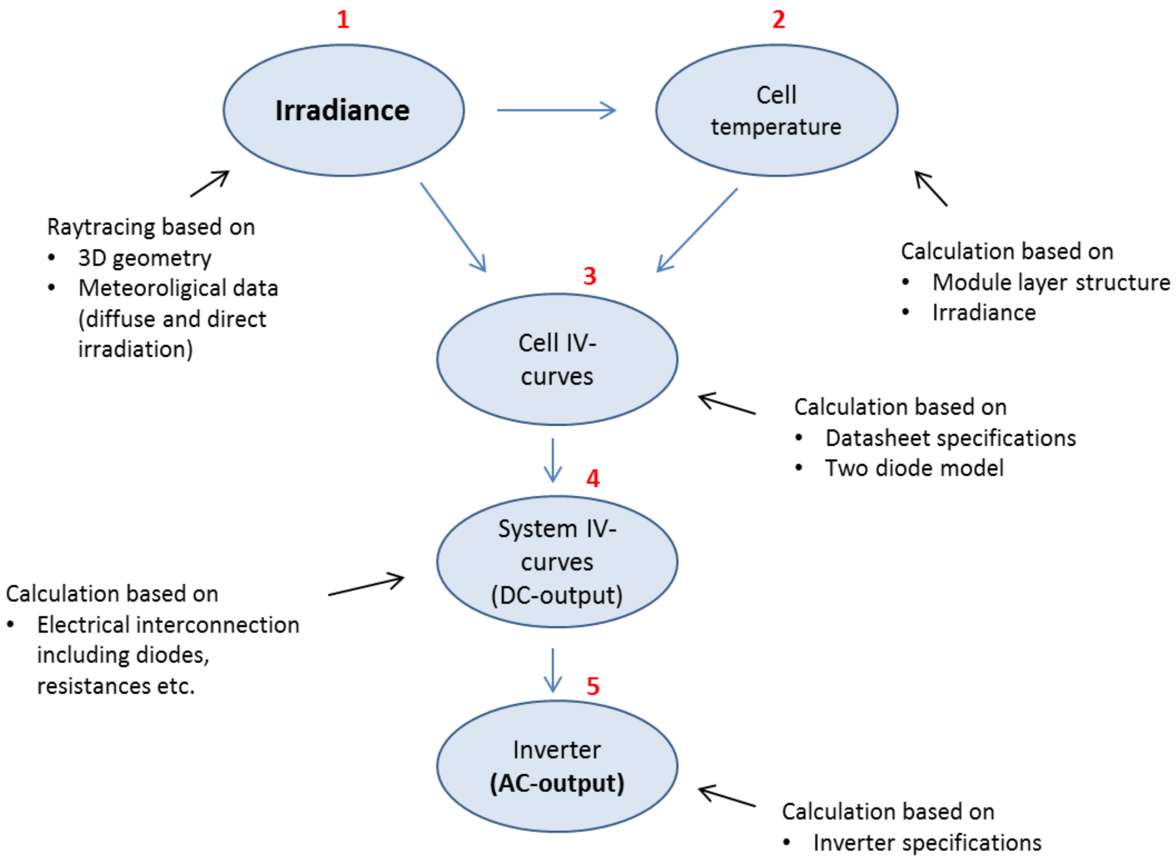

Figure 1: The BIPV simulation tool chain. Starting from the building and BIPV system geometry and meteorological data, the time dependent electrical yield of the system is calculated.

Step 1

In step 1, the time dependent irradiance on each solar cell of the (planned) BIPV system is calculated via ray-tracing using the open source software Radiance. As an input, meteorological data of the site including global horizontal and diffuse and/or direct horizontal irradiance and a 3D building model is required. The 3D building model has to be available in a Radiance geometry file. As in the context of Building Information Modelling (BIM) the Industry Foundation Classes (IFC) are an open format for exchange of BIM models, a parser from IFC to Radiance was developed. Thus, architectural models in widely used BIM software tools like Revit or Archicad, which provide an IFC export function, can be used to create the input for step 1. The output of step 1 is the irradiance on each PV cell (not module) at each time step. This is an important basis also in the planning phase in order to decide at which positions of the building skin BIPV can be a cost and energy efficient solution. Apart from BIPV simulation, this step can also be used for other building simulation tasks like calculation of solar gains and daylighting simulation.

As an example, Figure 2 shows a 3D model of a building in IFC format (visualized by Solibri) and in Radiance format (visualized by rshow).

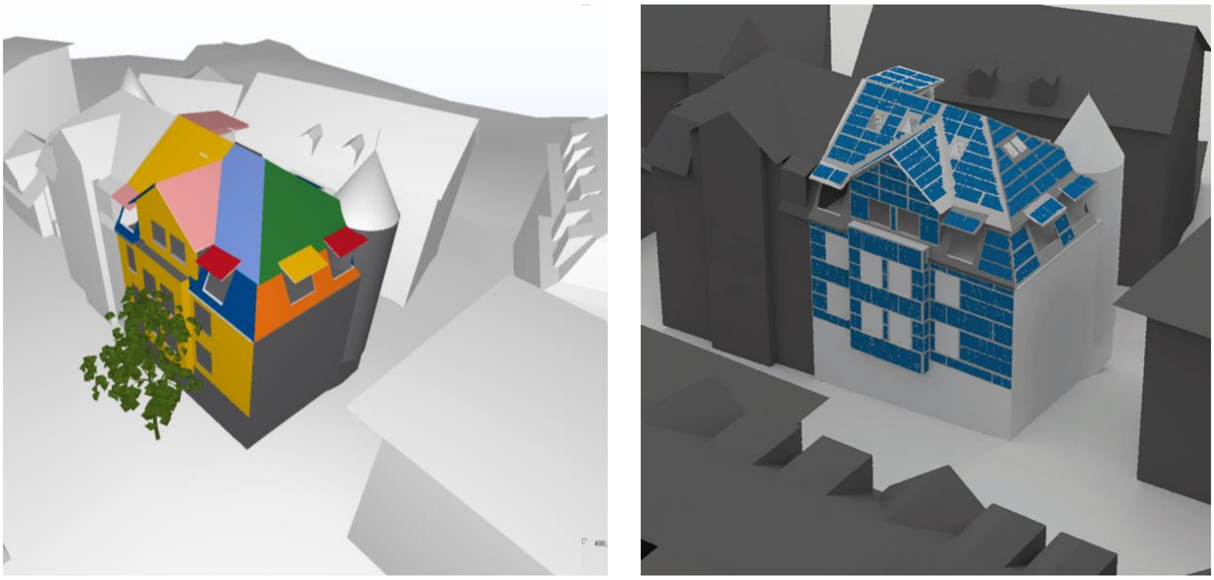

Figure 2: Example for the geometry translation from IFC to Radiance. On the left a visualization of the architectural IFC file (with Solibri, with pseudo-colors due to wrong material definitions). On the right the translated and post-processed Radiance file (visualized with rshow). The radiance file has been processed after the translation: Removal of tree, adding PV-panels, adjusting material properties for ray-tracing.

For another case, four orientations were available for BIPV. Figure 3 presents the result of the irradiance calculation for 360 sensor points on the building envelope. Based on such an analysis, the best-suited positions can be chosen for BIPV.

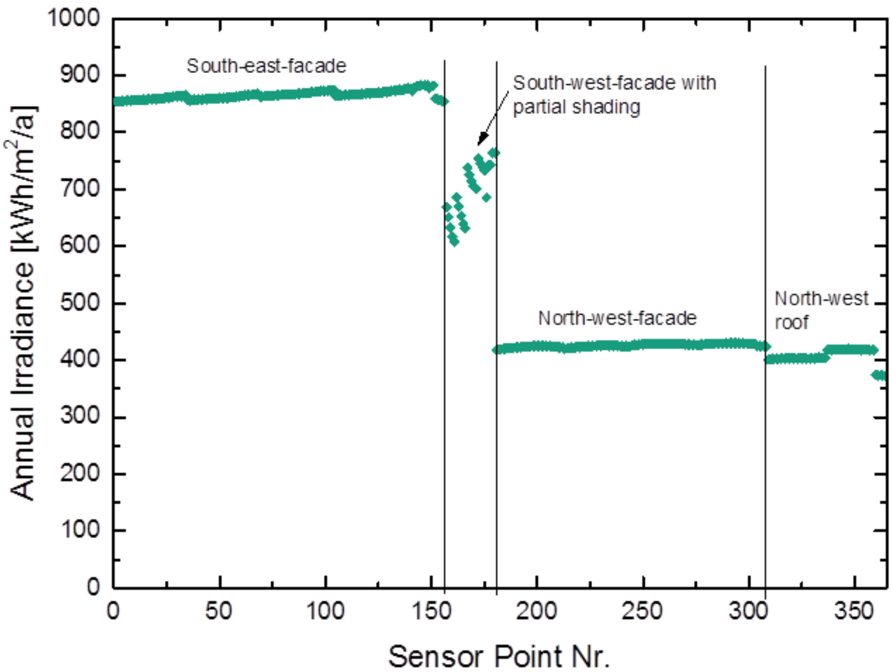

Figure 3: Example result for the irradiance calculation via ray-tracing in step 1. For various sensor points on the building skin (where PV-cells could be applied), the irradiance values integrated over a whole year have been calculated. Based on such a calculations, it can be decided where BIPV is a good solution. Also partial shading effects due to neighbouring buildings are included.

Step 2:

In the second step, the cell temperature is calculated for all time steps and all cells. As input, the previously calculated irradiance is used. Depending on the actual module layer structure, a simple linear model (for laminated modules) can be used or a more detailed simulation of the layer structure (for complex façade elements) has to be applied. For such a more detailed layer model, heat capacities and heat transfer coefficients of the individual layers of the BIPV system and additional layers that might be behind the module are needed as input. Figure 4 shows an example temperature simulation for the temperature at the backside of BIPV modules in comparison to a measurement for 5 days.

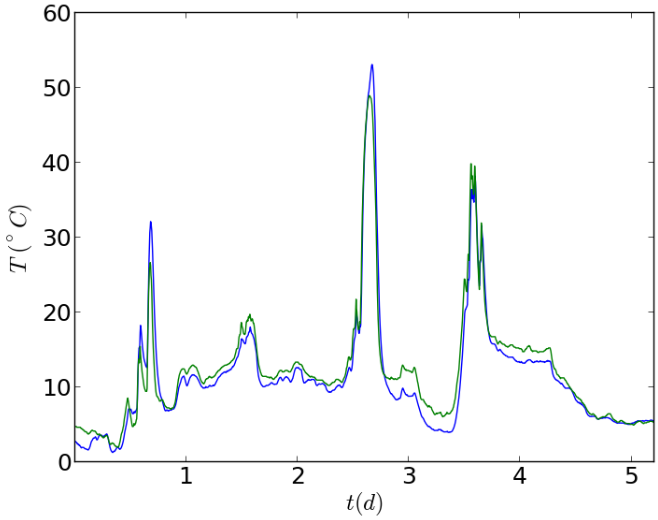

Figure 4: Temperature simulation (blue line) compared to measured temperature (green line) at 5 days. High irradiance on day 3 leads to high module temperatures. This is relevant to the module performance but also for temperature simulation of the building.

Step 3:

The cell IV curves for all relevant levels of irradiance and temperature are calculated based on the two-diode model extracted from the data sheet specifications of the PV manufacturer. They are stored in an IV-database in order to have all possible IV-curves for all temperature-irradiance combinations occurring available for the next step.

Step 4:

The system IV-curve is calculated based on the electrical interconnection of the individual cells. This results in the DC output of the system. In this step, optimization of the interconnection can be realized, especially when partial shading occurs. In addition, safety-related issues like hot spots can be detected within this step and the BIPV system design can be adjusted accordingly. As the DC output of all system levels (cells, modules, strings, sub-systems, and system) is calculated, a reasonable concept of using the output in the building context can be developed. Besides feeding the total output into the grid using an inverter (see step 5), also parts of the system could be used to directly supply technical components of the building (either with DC or AC), especially the electricity demand of FFG and RIWs.

Step 5:

Considering the inverter specifications, the AC output is calculated. The dimensioning of inverters can be optimized in this step. The resulting AC output is the final output of the simulation chain and can be used for further building simulation programs that need exact numbers for the time-dependent energy production by the BIPV system.

With this simulation chain, we have a tool to simulate also very complex BIPV systems. This enables a fully flexible integration of BIPV where it is needed to reach the ZEB standards. It generates input for other building simulation tools and thus allows for a detailed planning of the combination of BIPV with other innovative technologies like FFG and RIW. One important part is to take into account the overall electricity demand of the FFG nZE building. If the BIPV yield can be directly used by the nZEB, this is typically very attractive from an economic point of view. If the BIPV provides sometimes more electricity than the nZEB needs, the local conditions for feeding PV electricity into the grid need to be considered.

In cases without shading, simple approaches can be used to calculate the PV performance. The conversion of BIPV electricity into alternating current is the normal way of integration into a FFG nZE building. Academically, the PV could be a part of a FFG curtain wall element and used to run the FFG pump with direct current, but for this, a DC/DC optimizer would be needed which is typically available only for larger PV fields. In this academic case, the FFG could only be operated when it is irradiated and not for example at night to heat or cool the building.

For the building energy performance simulation and if shading can be neglected, one PV element is needed for each orientation of the FFG in order to calculate the PV performance and the mass flow which is generated by the pump. This acts as input data for the simulation model of the FFG in the building simulation, subsequently.

Case studies

To show the versatility and flexibility of the developed tool chain, in the following, results of three example BIPV-projects are presented. All three examples are real building projects in Southern Germany and Northern Switzerland, which can be a good market for FFG and RIW.

1.) Yield prediction for façade-integrated BIPV system A

For the building, for which Figure 3 shows the irradiance analysis, a yield prediction for a BIPV system was conducted. The north-west-façade and the north-west-roof were excluded, as based on the irradiance analysis it was decided that a BIPV system for these expositions is not cost-efficient. For the large south-east façade and the small and partially shaded south-west façade a BIPV system with 12 different strings and 4 inverters was designed. Table 1 summarizes the predicted yield for all the sub-systems. The time-dependent power output of the system is available to be integrated in further building simulations. Based on the yield prediction, also an evaluation of economic efficiency can be done.

Table 1: Result of the yield prediction for BIPV system A, installed at a south-east facade (1-9) and a south-west facade (10-12) that is partially shaded and therefore has a lower specific annual yield.

Sub-system No.	Annual Yield [kWh]	Specific Annual Yield [kWh/kWp]
1-8	17507.8	799.9
9	3890.6	799.9
10	900.5	740.6
11	1022.1	672.4
12	911.5	599.7

2.) Design and monitoring of a façade-integrated BIPV system B

For a further BIPV system, a similar yield prediction was done. The system has been monitored after installation and Figure 5 shows a comparison between measured and simulated values for one string (Maximum power point current I_{mpp}, voltage V_{mpp} and power P_{mpp}). The scatter plots show the values for all time steps within one year. The good agreement validates the simulation tool chain. By comparison between simulation and measurement, also malfunction of the system can be identified.

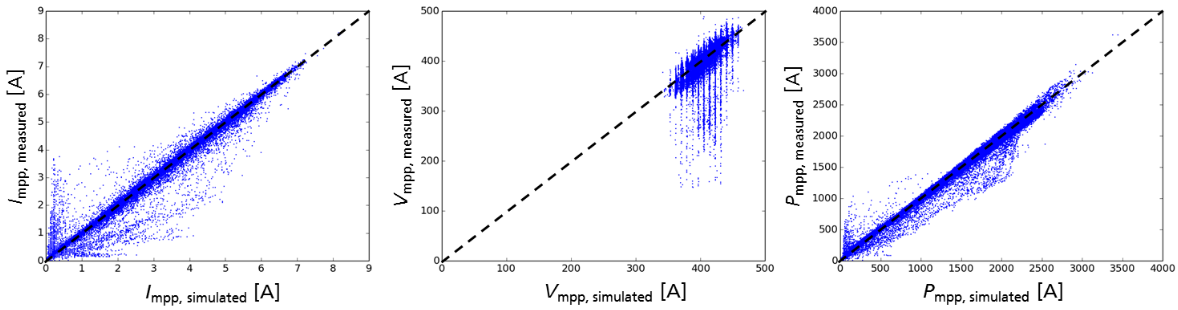

Figure 5: Comparison of simulated and measured DC-output of one string of BIPV system B.

3.) Design and yield prediction for a complex façade- and roof-integrated BIPV system C

The very complex BIPV system C, depicted in Figure 2 on the right, has been designed and optimized using the developed tool chain. Due to several different module orientations and sizes, combined with partial shading at different times for many modules, makes it challenging to decide which modules can be interconnected to strings, which strings can be connected in parallel and which inverters should be used. Answering these questions is important with respect to yield optimization but also with respect to system safety. Table 2 shows the resulting system designed using the tool chain. For each sub-systems (A-N) one small inverter converts the DC-output to AC. Knowing the output of each module in the simulation, modules suitable for series-connection have been identified. Thus, the mismatch of series-connected modules has been minimized and overall a system with 27.94 kWp has been designed and an annual yield of 14328 kWh has been calculated.

Table 2: The optimized BIPV system C.

Sub system	Inverter input ports	No. of PV cells	No. of module orientations	Nominal power [Wp]	Calculated DC-output per kWp and year (without inverter)	Calculated mismatch losses
A	6	613	2	1951.8	472.2	7.0%
B	3	296	1	942.5	375.1	12.3%
C	5	901	4	2868.8	796.2	3.6%
D	6	921	5	2932.5	601.8	2.0%
E	3	288	1	917.0	195.1	16.6%
F	3	405	3	1289.5	364.2	8.6%
G	6	634	3	2018.7	626.9	3.0%
H	5	744	3	2368.9	804.3	2.5%
I	6	720	2	2292.5	908.0	1.4%
J	6	830	1	2642.7	421.1	9.4%
K	5	802	1	2553.6	404.8	13.8%
L	5	600	1	1910.4	403.4	11.4%
M	5	528	1	1681.2	385.8	18.5%
N	4	494	1	1572.9	415.7	16.5%

Especially the last example (BIPV-system C) demonstrates that the developed tool chain can be applied very flexible also to complex BIPV systems in combination with FFG in nZEB.

3 Degree of Progress

There are no deviations from the work plan except that the preparation of this report was delayed by a few days because of limited available of the best BIPV experts.

4 Dissemination

These results will be shared with the consortium partners in order to prepare for the next meeting.