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Result of modelling and BIPV strategies for every demo site

Project Report

TECNALIA, BEAR, NOBATEK, CADCAMation, ACCIONA

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Summary

This document comprises the modelling description and simulation results of the different demo buildings in terms of (1) thermal performance using ENERGYPLUS, (2) electricity generation using PVSITES BIPV modelling tool and (3) economic performance using PVSITES planning tool.

Acknowledgements

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Disclaimer

Contents

Tables

Figures

1 EXECUTIVE SUMMARY

1.1 Description of the deliverable content and purpose

This document comprises the modelling description and simulation results of the different demo buildings in terms of (1) thermal performance using ENERGYPLUS, (2) electricity generation using PVSITES BIPV modelling tool and (3) economic performance using PVSITES planning tool.

The objective of the presented analysis was to evaluate the different alternatives proposed in subtask 8.1.2 regarding BIPV integration, electrical layout configuration, and operation strategy to support the final selection of the most suitable one. However, it is important to note that final design was mostly determined by other constraints, like the availability of commercial battery packs for selected storage capacities.

Firs of all, section 2 gathers a brief description of the different demo sites, their location and available surface for the BIPV generator as starting point for solar resource analysis.

Section 3 provides results about the impact of the PVSITES BIPV solutions on the demo-site building thermal behaviour. The ENERGYPLUS simulation program has been used to model the demonstration site buildings. BIPV products are modelled in two ways: (1) opaque BIPV integrated as cladding solutions or mounted with an air gap are simulated using the “NaturallyVentedCavity” object in EnergyPlus and (2) semi-transparent BIPV integrated as curtain walls are modelled using an “equivalent” glazing object in the program. In order to assess the impact of BIPV systems on the demonstration sites behaviours, the “heat needs” and “cooling needs” indicators are used to estimate the effect on the building energy consumption. The Givoni indicator is used to estimate the impact on the occupants’ thermal comfort. For each demo site thermal simulation hypothesis and results are shown. From these results, it is stated that the PV installation does not affect the overall building heat needs in demo#1, demo#2, and demo#5. However, in demo#6 – Tecnalia building, ONYX transparent product has a non-negligible impact on the building thermal behaviour and on lighting availability. The addition of PV cells in front of the windows reduces both visible and mid-range solar radiation. Regarding thermal needs, the cooling needs will be reduced while the heat needs will be increased. For the part of the building that has been modelled, the overall balance indicates a reduction of 5% in thermal needs (heating + cooling) for the 96 modules system and of 3% for the 72 modules installation. Obviously, carports of demo#3 are excluded from this study, as well as demo#4 CRICURSA building, where BIPV impact on such a huge hangar is expected to be negligible. Furthermore, required information about heat sources like ovens used in the industrial process and details about forced air ventilation system were not available.

Section 4 explains simulations carried out with PVSITES BIPV modelling tool to estimate energy yield and BIPV generation profile on hourly basis. For each demo site, the different steps are presented: (1) introduction of environmental information, (2) irradiance simulation, (3) configuration of BIPV layouts, (4) inverter selection and wiring and (5) simulation results. No critical issues in demo#1 were detected. In demo#2, though EHG pavilions facades are supposed not to be the better location for PV production according to simulation resutls, other constraints imposed their selection. The carports of demo#3 has been the greatest challenge since modelling long curved CIGS modules was necessary. Demo#4 CRICURSA’s roof was supposed to be the better location for PV production in this area, though heat losses are significant. In demo#2, demo#5 and demo#6, since BIPV generators are installed in vertical façades, diffuse irradiance generated from albedo effect is confirmed to be very significant for electrical production.

Finally, section 5 describes the parametric analysis carried out by the PVSITES planning tool, running energy simulations for a whole year under different scenarios of storage capacities and energy management strategies. Firstly, hypothesis and assumptions for each demo site are explained, including BIPV generation profile estimated in section 4, consumption profile and economic conditions in each case. Then, results are examined to select the best solution according to economic criteria. In demo#1, demo#2 and demo#5 BIPV generator payback period is quite long mainly due to scarce solar resource and low direct self-consumption rate. A storage system can be used to reach quite higher self-consumption rate. However, this increases payback period since it is not possible to take great advantage from electricity tariff variability since it remains constant during daytime. PVSITES predictive energy management strategy allows to reduce significantly power peak consumed from the grid helping to grid planning and operation, but this peak-shaving is not currently remunerated in these countries. Nevertheless, in demo#4 CRICURSA building BIPV generator payback period is 9 years mainly due to high self-consumption rate and energy yield. Although storage hardly rises self-consumption rate and related savings, it significantly increases profitability of the whole system thanks to the additional incomes from peak-shaving. In demo#2 and demo#6 neither storage capacity nor advanced EMS makes sense in absence of PV excess.

It is important to remark that sections 4 and 5 of this deliverable have been updated with figures of final BIPV system design in order to check the reliability of PVSITES BIPV modelling and planning tool.

1.2 Relation with other activities in the project

Table 1.1 depicts the main links of this deliverable to other activities (work packages, tasks, deliverables, etc.) within PVSITES project. The table should be considered along with the current document for further understanding of the deliverable contents and purpose.

Table 1.1 Relation between current deliverable and other activities in the project

Project activity	Relation with current deliverable
Subtask 8.1.1.	During performance assessment of every demo site in subtask 8.1.1, an energy analysis was carried out to identify real thermal and electrical behaviour of each building. All the collected information has been an essential input for developing modelling described in this deliverable.
Subtask 8.1.2	In subtask 8.1.2, different alternatives were proposed regarding BIPV integration, electrical layout configuration, and operation strategy in each demo site. All of these have been modelled to support the selection of the most suitable one in each case.
Subtask 8.1.4	This deliverable gathers the modelling and simulation results according to the final design of BIPV implementation on demo sites selected in subtask 8.1.4.
Task 3.6	BIPV modelling strategies of crystalline silicon modules have been developed in task 3.6 and described in deliverable D3.7.
Task 4.3	BIPV modelling strategies of CIGS modules have been developed in task 4.3 and described in deliverable D4.4.
Task 6.1	The planning tool used for the economic performance simulations presented in section 5 was developed in task 6.1.

Task 7.1	The BIPV software tool used for the BIPV modelling described in section 4 was developed in task 7.1.

1.3 Reference material

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1.4 Abbreviation list

BOS – Balance of System

CAPEX – Capital Expenditures

CIGS - Copper Indium Gallium Selenide

BAPV – Building Attached Photovoltaics

BIPV – Building Integrated Photovoltaics

DC – Direct Current

OPEX – Operational Expenditures

PV - Photovoltaics

2 DEFINITION OF DEMO-SYSTEMS

2.1 DEMO#1 – Format D2 house, single house in Mons

PVSITES Demo-Building 1, provided by the partner the partner FORMAT D2, is a residential building for private and professional use. The main location data are:

- Address: Rue du Banc de Sable, 22, Stambruges (Belgium).
- Geographical coordinates: 50° 29' 58,7'' N // 3° 42' 52,9'' E.
- Elevation: 68 m.

Figure 2.1: DEMO#1 – FORMAT D2 residential and professional building in Belgium

The demo-system will consist on a BIPV roof composed by CIGS on steel modules designed and manufactured by FLISOM. The module design has been specially conceived to facilitate the installation of the BIPV tiles on the sloped roof structure, to efficiently resolve the boundary areas and to contribute to the waterproofing and the thermal performance of the roof as a whole. The constructive and energy passive functionalities of the BIPV roof will come to further improve the energy performance of a building, already designed on the basis of the sustainable architecture, environmental friendly and according with the local style and uses.

The new BIPV roof system will be SSW oriented, with 30º tilt, and a total occupied area of 110 m^2.

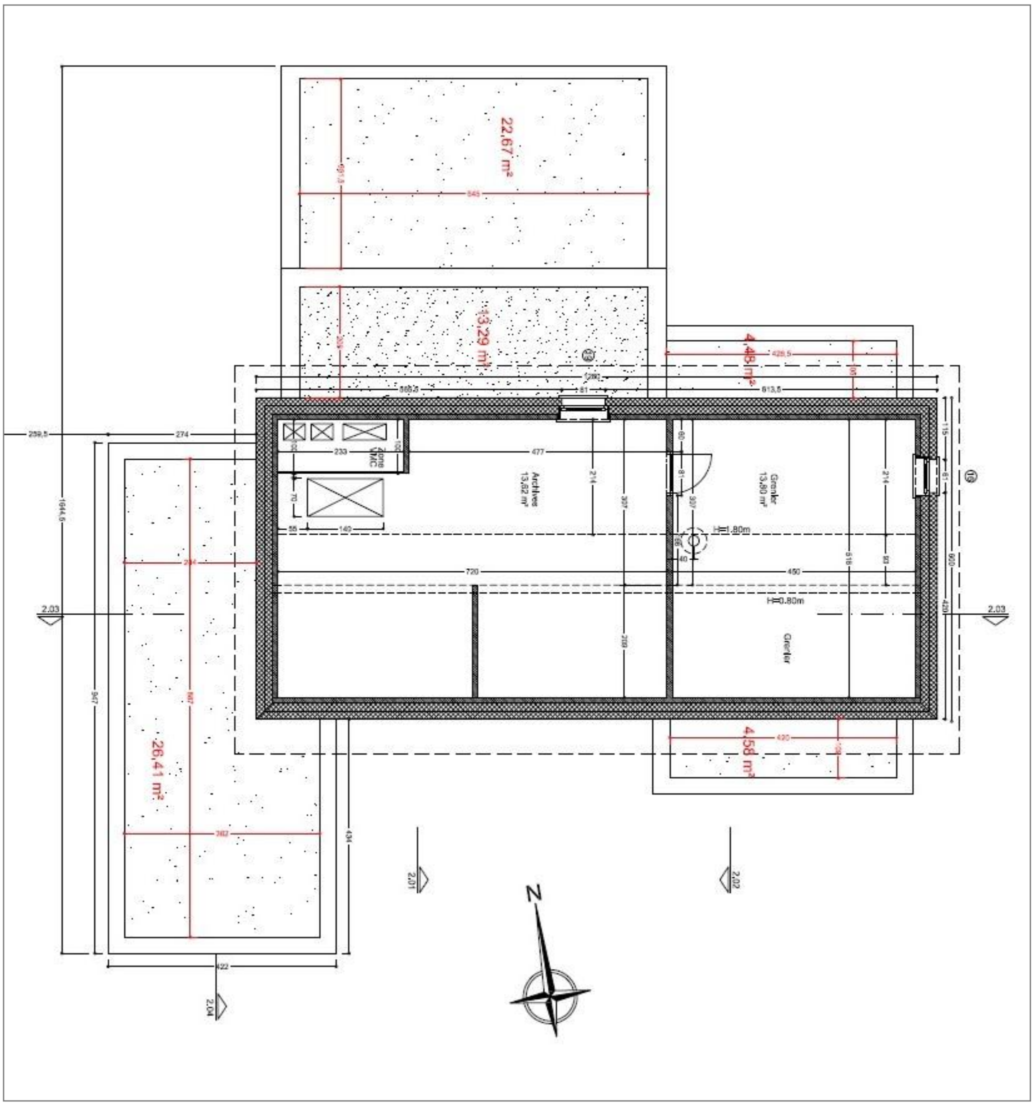


Figure 2.2: DEMO#1 – FD2 Floor plan of the Belgian Demo-building

2.2 DEMO#2 – EHG,educational building in Genève

The PVSITES Demo-site 2, provided by the partner FLISOM, is a set of buildings which houses the hotel school EHC (École Hôtelière de Genève). The main location data are:

- Address: Avenue de la Paix 12, 1202, Genève (Switzerland).
- Geographical coordinates: 46°13'36.8"N // 6°08'17.4"E.
- Elevation: 431 m.

Figure 2.3: DEMO#2 –École Hôtelière de Genève (school facilities and students hotel)

The BIPV system foreseen in the École Hôtelière de Genève consists of several ventilated façades built with PV modules laminated on metal piece, designed and manufactured by FLISOM. The pavilions 1 and 2 of the complex will host the systems.

The east façade of the Pavilion 1 has two rows of windows in the ends of the building and a central curtain wall in the middle, from the top to the ground. The BIPV systems will be installed in the 2 available areas between them.

The west façade of the pavilion 2 has two centred vertical rows of windows, also from the top of the building to the ground. The BIPV systems will be installed in the 3 available areas between them.

Figure 2.4: DEMO#2 –EHG East and West façades of the Pavilions 1 and 2, respectively

2.3 DEMO#3 – CARPORT of EMPA facilities in Zurich

The Demo 3 will consist in a PV carport system, with CIGS on steel modules, designed and manufactured by FLISOM.

The initially selected Demo-site 3, an existing carport pending of a retrofitting located in the parking of EMPA Campus, in Dübendorf (Switzerland), has been finally discarded because of several reasons:

- The asbestos covering should be removed, issue not considered in the budget
- The carport use is private, and the project would not compensate the operating losses during the installation works.
- The system would be shadowed by nearby trees, reducing the power production.
- Visibility form the street is not good, reducing the dissemination impact.

With the opening of the Empa mobility demonstrator (MOVE, https://www.empa.ch/web/move) on the Empa campus a much more prominent location came up and Flisom reached an agreement with Empa to allow a construction of a PV carport in this platform. While the negotiations with EMPA were ongoing Flisom looked for alternative solutions. With EKZ, the local electricity provider for about 1 million people in the canton of Switzerland, Flisom found an excellent collaboration opportunity. EKZ is interested in building a PV carport in from of their building in Seuzach.

Hence, two PV carports will be installed in the following locations:

- EMPA Campus.
  - Address: Überlandstrasse 129, 8600, Dübendorf, Zurich (Switzerland).
  - Geographical coordinates: 47° 24' 08.9" N // 8° 36' 40.0" E.
  - Elevation: 433 m.

Figure 2.5: DEMO#3 Location of the demonstrative PV carport in EMPA Campus, Switzerland

- EKZ facilities.
  - Address: Deisrütistrasse 12, 8472 Seuzach, Switzerland.
  - Geographical coordinates: 47° 32' 0'' N // 8° 44' 0'' E
  - Elevation: 450 m.

Figure 2.6: DEMO#3 Location of the demonstrative PV carport in EKZ facilities, Switzerland

2.4 DEMO#4 – CRICURSA industrial building in Barcelona

PVSITES Demo-Building 4, provided by the partner CRICURSA, is an industrial and office building complex. The main location data are:

- Address: PI Coll de la Manya, Camí de Can Ferran s/n, 08403, Granollers (Spain).
- Geographical coordinates: 41° 35' 14.9" N // 2° 16' 01.7" E
- Elevation: 153 m.

Figure 2.7 DEMO#4 – CRICURSA, Industrial and office building complex in Spain

The BIPV roof system will be placed in the south face of a double-sloped roof of a recently built pavilion (orientation: +2°; tilt 6°). The final location allows avoiding the nearly shadows projected by the roof parapet on the front and back façades.

The new building’s roof is divided into 10 sections made up of polyurethane panel *AIS-3G of 50 mm* of different width separated by transversal skylight elements *Arcoplus 1000 flat*.

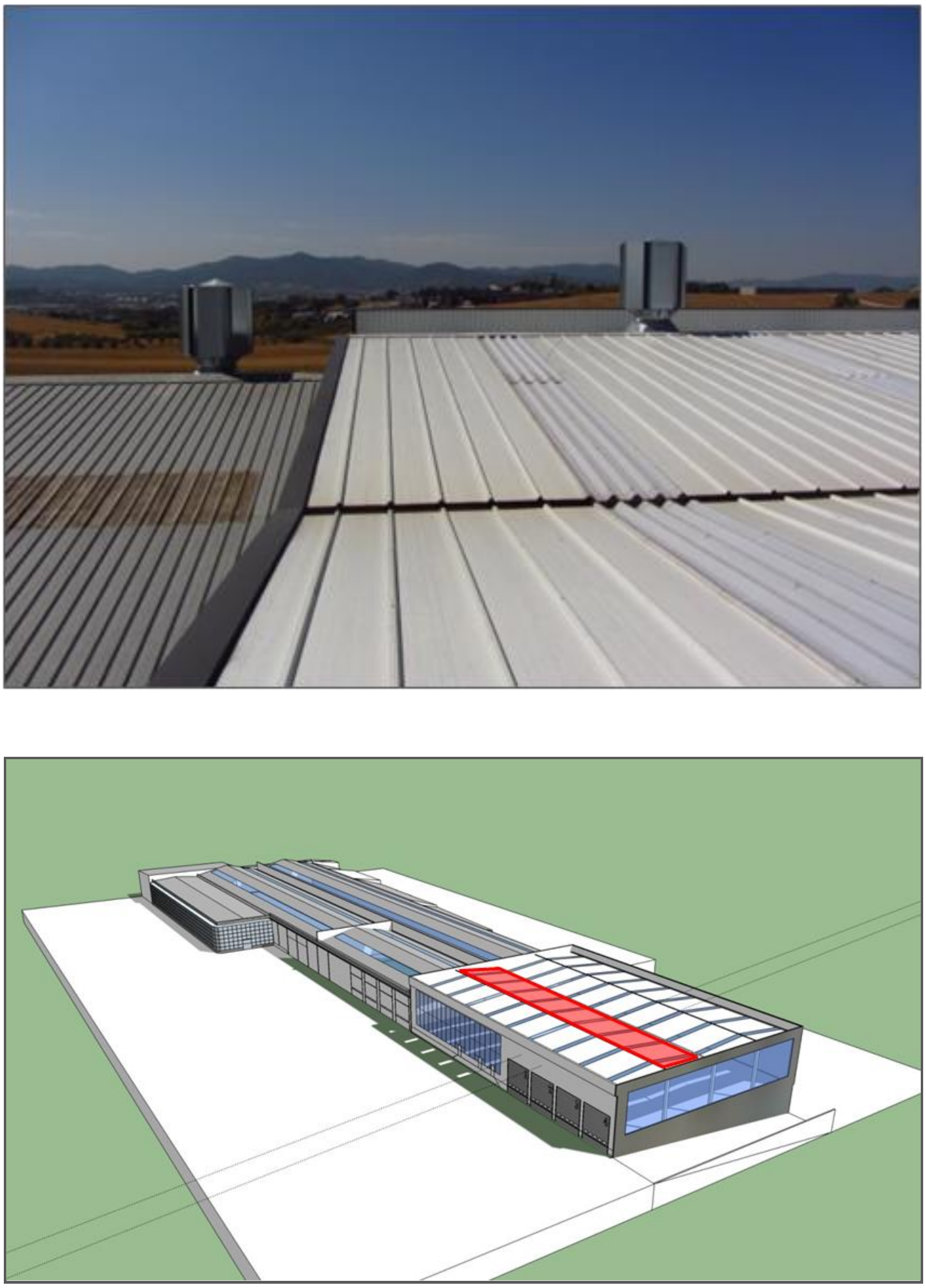


Figure 2.8: DEMO#4 – CRICURSA, chosen area to implement the BIPV system

Some undesirable shadows from the parapet might affect the PV modules performance. This inconvenient has been assessed through the simulations carried out by CADCAMation on the basis of a 3D model of the demo building and system. For this reason, the PV modules will be able to be slightly moved away from the roof edges.

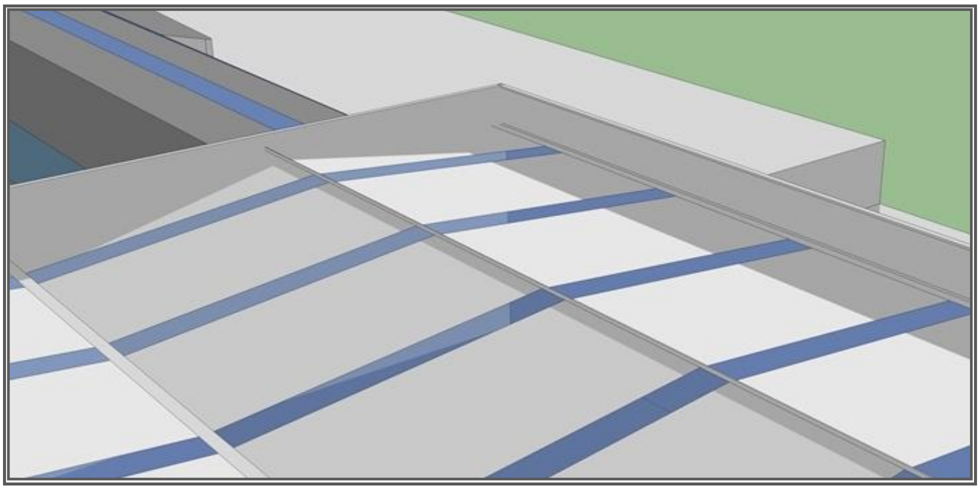


Figure 2.9: DEMO#4 – CRICURSA, roof parapet shadowing effect on the available area for PV

2.5 DEMO#5 – Vilogia apartments building in Lille

PVSITES Demo-Building 5, provided by the partner VILOGIA, is a residential storey block, and it is currently in a retrofitting process.

- Address: 12-14, rue du Docteur Laennec, 59139, Wattignies (France).
- Geographical coordinates (sexagesimal): 41° 35' 14.9" N // 2° 16' 01.7" E.
- Elevation: 153 m.

Figure 2.10: DEMO#5 – Vilogia, Residential 8-storey building, provided by VILOGIA

The BIPV ventilated façade system will be placed in SSE façade, which is currently made from the top to the ground by a brick cladding and include a vertical windows row in the west side. Roofs are provided with foam glass insulation, a bituminous sealing and a gavel protection. Brick wall includes polystyrene insulation and air chamber throughout the air can flow. Originally the openings were made of wood, but some of them were replaced by PVC double glazing units. All of them will be replaced in order to improve the thermal insulation during the retrofitting works.

The SSE façade brick cladding will be removed almost in their entirety, as part of the retrofitting works, leaving the inner concrete wall exposed. The foreseen BIPV system will be installed on this wall. The project will have to provide a complete façade solution that not only introduce PV but also ensure thermal insulation and waterproofing.

In the other hand, in order to avoid shadows over the PV modules from the high trees existing in front of the façade will be removed.

2.6 DEMO#6 – TECNALIA office building in San Sebastian

PVSITES Demo-Building 6, provided by the partner TECNALIA, is an office building with engineering and chemical laboratories.

- Address: Paseo Mikeletegi 2, San Sebastian (Spain).
- Geographical coordinates (sexagesimal): 43° 17' 10.9" N // 1° 59' 05.6" W.
- Elevation: 132 m.

Figure 2.11: DEMO#6 – TECNALIA offices and labs in San Sebastian

The BIPV system addressed to be installed in TECNALIA will consist on a double-skin over the existing curtain walls with c-Si back contact laminated glass modules, by ONYX.

The chosen façades, SSE & S, are composed of large curtain walls; each one divided in two zones corresponding to the office areas of the first and the second floors. Both façades have a polygonal section made up of 6 vertical windows rows with different orientations and an extra one facing east. The entire curtains walls will be covered by PV, with the exception of the seventh rows which present an inappropriate orientation. The curtain walls are composed of an aluminium structure with clear double-glazing units. There is one horizontal windows row per floor with openable windows; all the others are closed elements.

3 DEMO SYSTEM AND BUILDING SIMULATION USING ENERGYPLUS

3.1 Methodology used for simulation at building level using ENERGYPLUS

3.1.1 Overall methodology and scope of the simulations

The aim of this section is to provide results about the impact of the PVSITES BIPV solutions on the demo-site building thermal behaviour. The results of the simulation could orientate the strategy of implantation of the PV systems, if the effects on the building energy consumptions (heating/cooling) or on the occupant thermal comfort is significant, regarding the electricity production.

The EnergyPlus simulation program is used to model the demonstration site buildings. This program developed by the Lawrence Berkeley National Laboratory is widely known and has been validated [1]. The graphical interface DesignBuilder is used for the model construction.

BIPV products are modelled in two ways:

- Opaque BIPV integrated as cladding solutions or mounted with an air gap are simulated using the “NaturallyVentedCavity” object in EnergyPlus. This model has been used and validated several times to simulate baffle or PV installation [2], [3].
- Semi-transparent BIPV integrated as curtain walls are modelled using an “equivalent” glazing object in the program. Glazing properties are experimentally defined (WP4).

The BIPV modelling strategies won’t be further described in this document as it is the objective of deliverables D3.7 (task 3.6 of WP3) and D4.4 (task 4.3 of WP4).

In order to assess the impact of BIPV systems on the demonstration sites behaviours, the “heat needs” and “cooling needs” indicators are used to estimate the effect on the building energy consumption. The Givoni indicator is used to estimate the impact on the occupants’ thermal comfort.

3.1.2 Indicators definition

3.1.2.1 Heating and cooling need indicator

The heat needs or cooling needs represent the amount of energy that needs to be injected or removed from a thermal zone to reach the temperature set-point. It can be viewed as the “ideal load” of the HVAC system. Therefore, they are good indicators to assess the effects on the building energy consumption.

However, it doesn’t necessarily give the impact on the actual building consumption as it doesn’t take into account the heating/cooling plant specifications (efficiency, inertia, regulation, etc.).

3.1.2.2 Thermal comfort indicators

The thermal comfort of building occupants is very hard to define, as it is a condition of mind related to a thermal environment. It varies from person to person according to physical and psychological parameters. However, according to the ASHRAE [4], the following 6 main factors can be defined:

1- Metabolic rate,
2- Clothing insulation,
3- Air temperature,
4- Radiant temperature,
5- Air speed,
6- Humidity.

For the PVSITES project, and in interaction with WP7 (BIPV software tool development), it has been decided to choose to use the Givoni thermal zones [5] to estimate people's thermal comfort during summer time. Contrary to the Predictive Mean Vote (PMV) or Percentage of Person Dissatisfied (PPD) [6], it is independent of the occupant clothing or metabolic rate and it only relies on the building thermal state (surface and air temperature, air speed, humidity). Moreover, according to Givoni [5], it is more suited to buildings where thermal comfort is obtained through passive solutions (natural ventilation, building inertia, solar protection, etc.). Hence it is a relevant complement to the cooling need indicator that will assess impact on active cooling solutions such as chiller plant. Below, an example of a projection of building summer thermal conditions on the psychrometric diagram with the 3 Givoni comfort zones is presented:

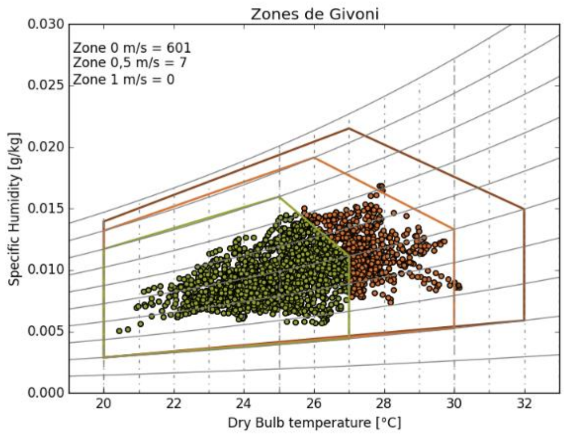


Figure 3.1 Givoni comfort zones for air speed ranging from 0m/s to 1m/s

It can be interpreted by analysing the number of hours when the indoor conditions go beyond a comfort zone which is defined for different air speeds. In France, several "Environment guidelines" use this interpretation to define level of performance [7], [8].

3.2 DEMO#1 – Format D2 house, simulation by ENERGYPLUS

The FORMAT D2 house is located in Belgium (Stambruges). The 219m² building holds both a residential and an office space. It is 3 storeys high and the last storey located under the slop roof facing south only contains the archive and the attic.

3.2.1 Simulation hypothesis

3.2.1.1 Building climate and environment

Figure 3.2 Satellite view of the FD2 house

The house seems to be surrounded by trees that may cause solar mask. However, due to the lack of more detailed information, they won't be modelled. On a thermal point of view, and regarding the objectives of Task 8.1, this approximation will not affect the comparison between the different simulations performed, nor the conclusions.

Considering the location of the house, the climate of the city of Brussels has been used for this study. The following graphs gather annual information on temperature and solar radiation level:

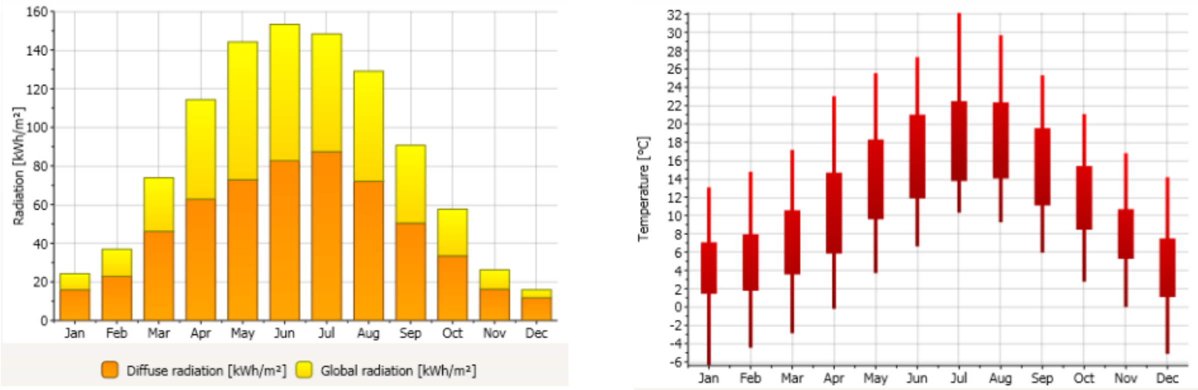


Figure 3.3 Brussels - Typical year temperature and radiation profiles

3.2.1.2 Building envelope

The building envelop hypotheses have been extracted from the PassiveHaus Excel file:

- External walls and roof have a conductivity inferior to 0.1 W/m².K. Cold bridges have been taken into account as an additional loss.
- Windows Solar Heat Gain Coefficient (SHGC) is ranging from 0.34 to 0.53, overall heat transfer coefficient (including frame) is ranging from 0.74 to 0.94 W/m².K.
- Infiltration rate is 0.51 Vol/h for a 50Pa pressure drop. According to the EN 13790, it can be modelled as a 0.066 constant Air Change per Hour (ACH).

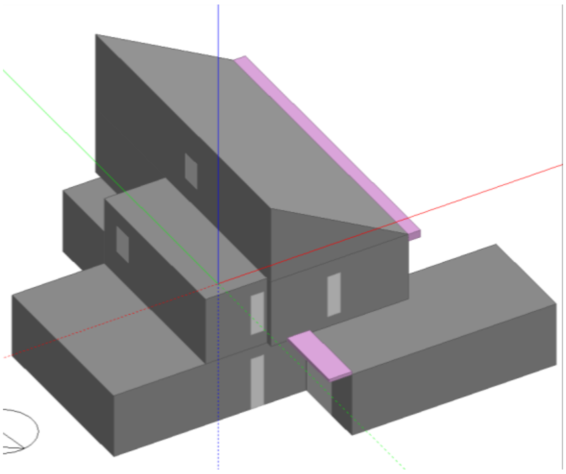


Figure 3.4 DEMO#1 – FD2 3D model view

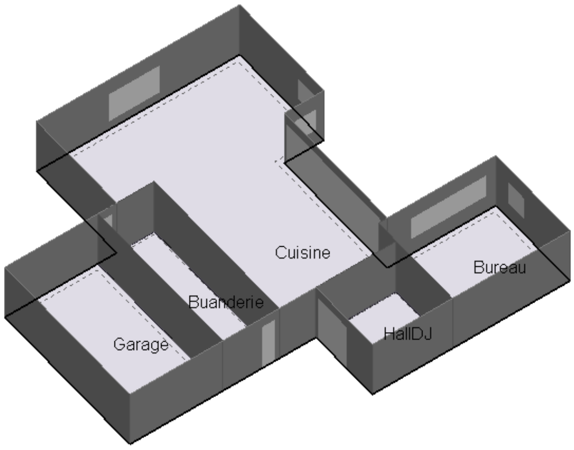


Figure 3.5 DEMO#1 – FD2 Ground Floor_Thermal Zones

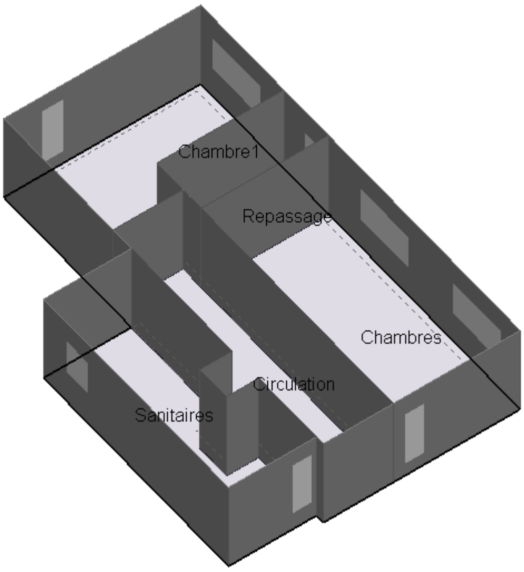


Figure 3.6 DEMO#1 – FD2 R+1_Thermal Zones

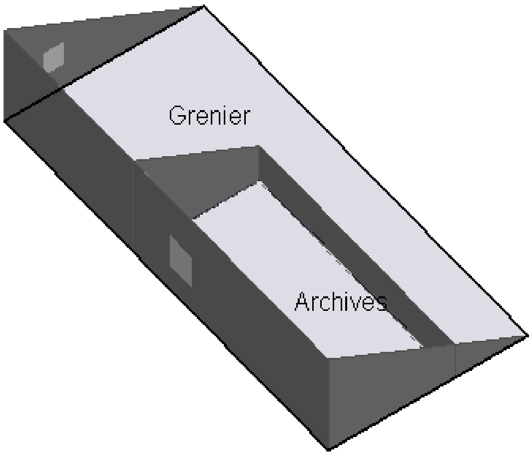


Figure 3.7 DEMO#1 – FD2 R+2_Thermal Zones

3.2.1.3 Internal heat gains

The FD2 house is equipped with several sensors that perform detailed measurement of the lighting and appliances use. This information have been gathered in a file provided by R2M for a period between January and May 2016.

For the whole house, the maximum power drawn by the appliances is 608W, and 52W for the lighting. The heat gains have been equally dispatched between the house main occupied rooms. It leads to the following ratio:

Table 3.1 FD2 internal heat gains

Internal heat gains		
People	0.01	pers/m² 80 W/pers
Appliance	3.05	W/m²
Lighting	0.26	W/m²

The schedules have been extrapolated from the measured data by creating a monthly average schedule. Full year schedules have been created and are represented in the figure below:

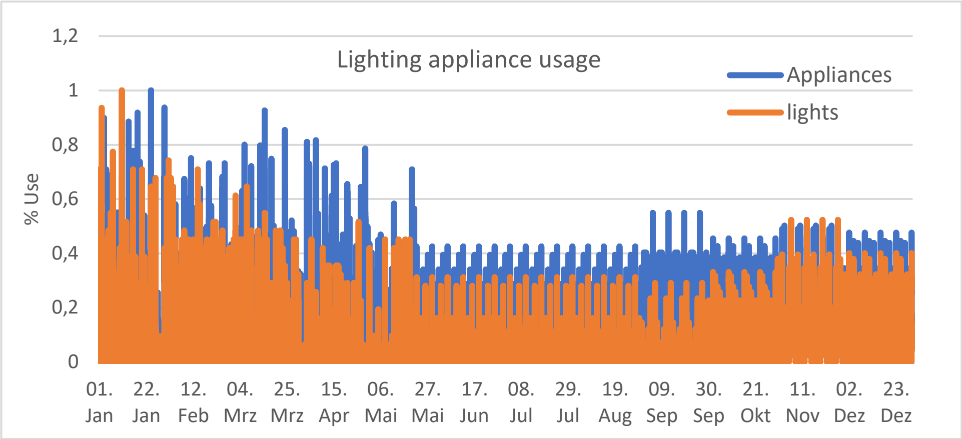


Figure 3.8 Appliances and lighting % usage of DEMO#1 – FD2

The month of December is constructed from the January data. It is composed of average weekdays, therefore peaks of power are erased and the profile looks different from the one of January, however both months are very similar.

3.2.1.4 HVAC equipment

For the building thermal simulation, ideal systems are considered. HVAC systems properties (efficiency, regulation, inertia) are not taken into account.

The house doesn't have any cooling equipment. During the winter, for every day, the heating set point is 21°C from 8:00AM to 21:00, while the set back is 17°C.

Concerning the ventilation system, the phpp file indicates a 352m^3/h for the building. This leads to a 0.066 ACH for each thermal zone (except the attic). The air change is handled by a dual flow Air Handling Unit (AHU) equipped with a 84% efficient heat exchanger.

The annual schedule used is derived from the measured data and is displayed below:

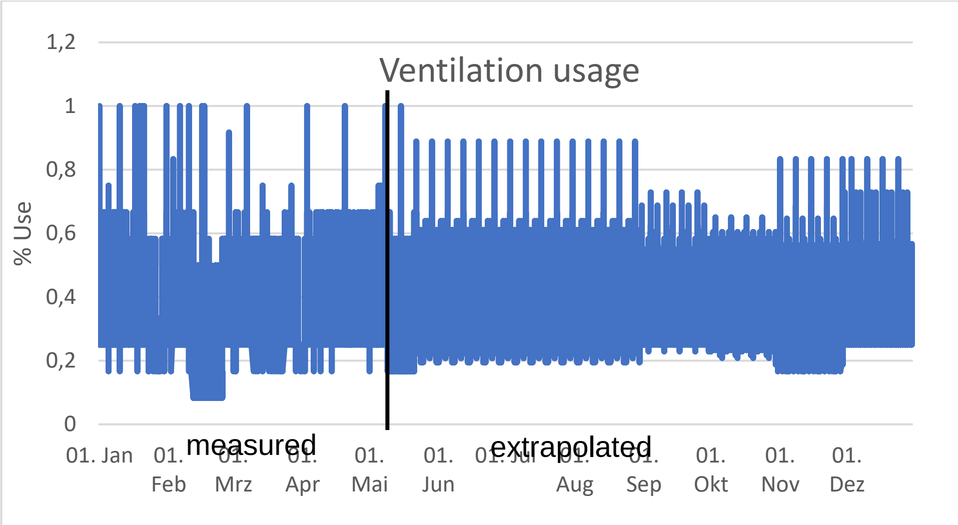


Figure 3.9 Ventilation % usage of DEMO#1 – FD2

3.2.1.5 PV installation

FLISOM X1 CIGS roofing shingle on metal product has been selected for this demo site. It will replace the actual tiles. A preliminary installation sizing has been performed and is described in deliverable D8.1: 75 modules representing 80m² of solar panels will be installed on the tilt roof facing South. They will be mounted according to the following scheme with a 5cm air gap between the solar tiles and the insulation material.

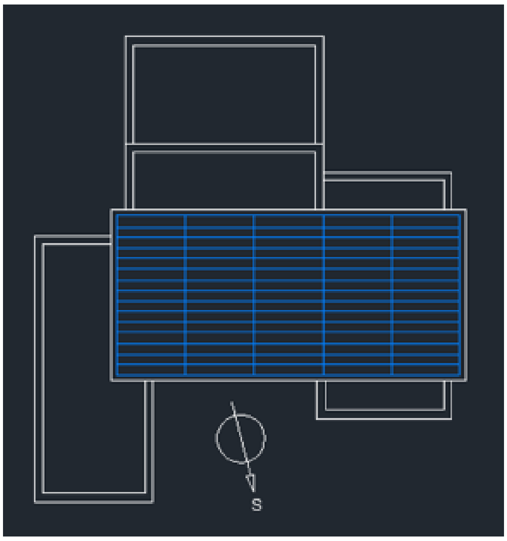


Figure 3.10 DEMO#1 – FD2 panel location

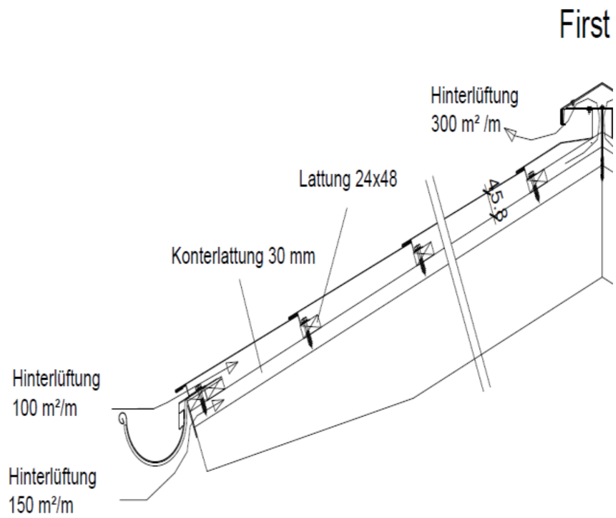


Figure 3.11 DEMO#1 – FD2 panel mounting system

In EnergyPlus, the installation will be modelled as a naturally vented cavity. The main hypotheses of the model are gathered and explained in the following table:

Table 3.2 PV module model configuration for DEMO#1 – F**D2**

Internal heat gains		
Area Fraction of Openings [-]	0	The tiles are perfectly adjusted and water proof. There is no opening.
Thermal Emissivity of Exterior Baffle Material [-]	0.9	External face emissivity is 0.9, while internal emissivity is 0.1. However, in the model, it is impossible to input the 2 emissivity values. This is a known issue of the vented cavity model, the baffle material properties are consider homogeneous. Specifying a low value will accurately model the infrared transfer between tiles and roof materials in the air gap, but will underestimate the transfer with the outside environment (sky). However temperature in the air gap is of great importance, as it will affect the insulation material integrity. We choose to model the system with a 0.9 emissivity which is the worst case scenario for the insulation material temperature.
Solar Absorptivity of Exterior Baffle [-]	0.8	According to FLISOM, the solar absorbance is around 92% for wave length ranging from 200nm to 1100 nm. Taking into account this characteristic, around 12% of solar radiations are converted into electricity; it leads to a 0.8 absorbance coefficient.
Effective Thickness of Cavity Behind Exterior Baffle [m]	0.05	According to plans
Roughness of Exterior Surface	Smooth	
Effectiveness for Perforations with Respect to Wind	0.42	These coefficients determine the air change rate of the air gap by buoyant and wind effect. Unfortunately, it is very hard to estimate a value, and most of the time these parameters are determined experimentally. Griffith [3] proposed values ranging from 0.25 to 0.6 for the Cv coefficient and 0.5 for Cd.
Discharge Coefficient for Openings with Respect to Buoyancy Driven Flow	0.5	

3.2.2 Simulation results

3.2.2.1 Impact of PV system on building heat needs

Simulations are carried out over a full year. For heat needs, the results are analysed for the heating period ranging from the 01/01 to the 01/05, and from the 01/10 to the 31/12. The main heat gains and heat losses are aggregated for the whole building and are displayed on the following figure:

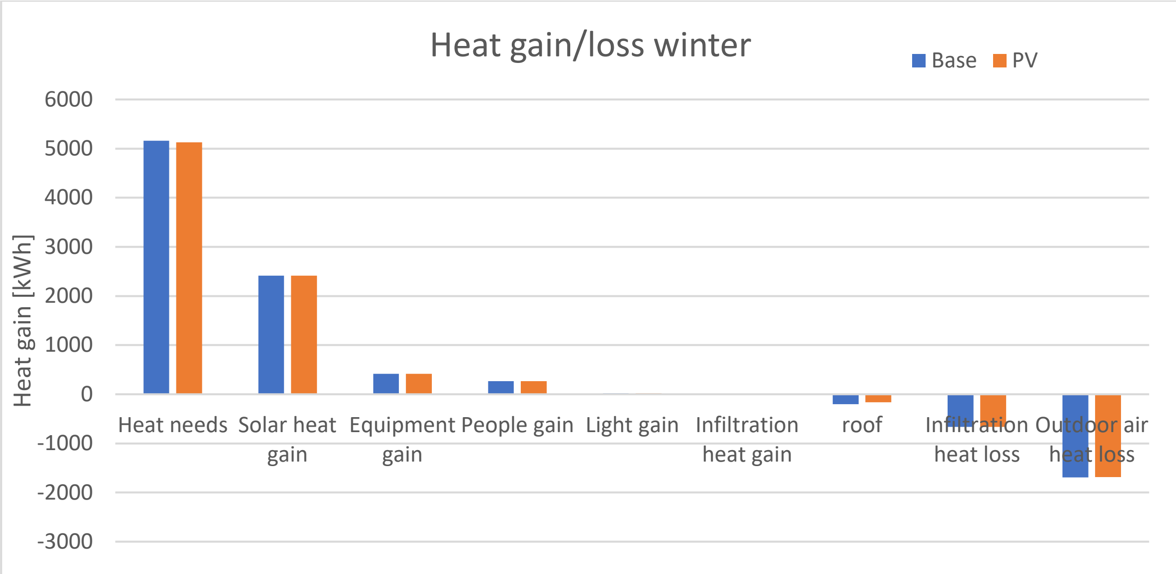


Figure 3.12 DEMO#1 – FD2 internal heat gains

From these results, we can tell that the PV installation does not affect the overall building heat needs. The difference of energy needs between the actual house and the building equipped with FLISOM products is less than 0.4%. This is negligible regarding the other approximations made for the simulations.

Regarding convection and long wave thermal heat transfers from the roof inside face to the adjacent room, the replacement of the actual tiles by solar panel impacts the transfers by 18%. However, the heat losses at roof level that sum the convective and radiative heat transfers are very low compared to infiltration or ventilation losses.

3.2.2.2 Impact of PV system on occupants' thermal comfort

Simulations are carried out over a full year. For thermal comfort, the results are analysed for the summer period ranging from the 01/05 to the 30/09. For each occupied thermal zone, the building thermal conditions (operative temperature and relative hygrometry) are cast on the psychrometric diagram. Below is an example for the office zone and for a sleeping room:

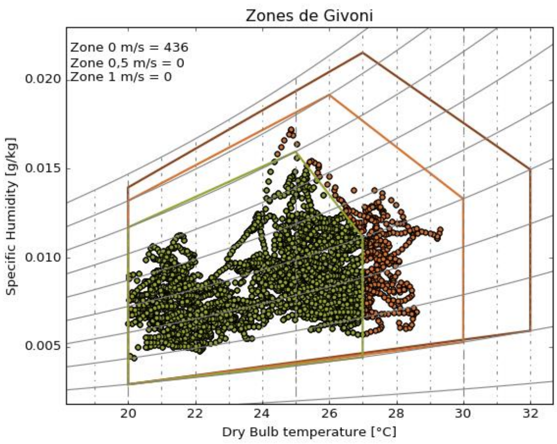


Figure 3.13 DEMO#1 – FD2 Thermal comfort for office space

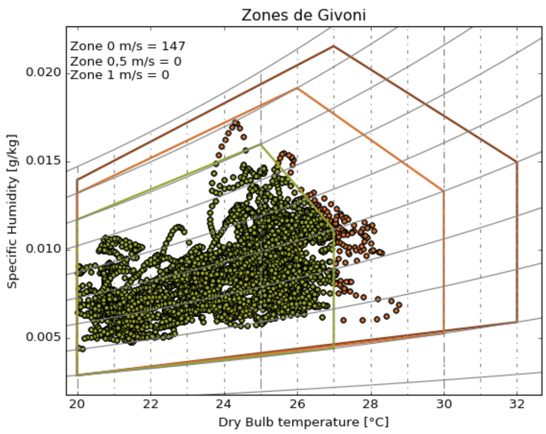


Figure 3.14 DEMO#1 – FD2 Thermal comfort for sleeping room 1

Two indicators are used to assess the impact of the solar PV installation on all the main thermal zones:

- The number of hours when the indoor conditions went beyond the first thermal envelop (0 m/s),
- The maximum operative temperature reached.

The table below shows the number of “first envelop overshoot” for each occupied zone with and without the PV installation and the maximum indoor operative temperature:

Table 3.3 DEMO#1 – FD2 internal heat gains

Level	zone	Base Givoni Overshoot	Pv Givoni Overshoot	Impact	Base Max temp	Pv Max temp	Max temp delta
R1	Bedroom 1	139	214	35%	27.8	28.0	0.17
R1	Bedroom 2	147	199	26%	28.8	28.9	0.16
RDC	Office	436	442	1%	29.3	29.3	0.01
RDC	Kitchen	525	553	5%	30.0	30.1	0.06
RDC	Hall	34	34	0%	27.1	27.1	0.02

Considering the results, the solar installation won’t have a strong impact on the rooms located at the ground floor.

At the first floor, a small impact can be seen on the bedrooms temperature. The number of hours the indoor conditions overshoot Givoni first envelope increases by 26% to 35%. However, the maximum temperature in these rooms does not increase by more than 0.17°C, and the mean operative temperature only increases by 0.14°C to 0.16°C. The Givoni indicator is very sensitive. A slight increase in air temperature can make thermal conditions switch from one comfort envelop to another. This will be further described in the deliverable D4.4 applying a sensitivity analysis to show the impact of the input parameters on the indicators.

These temperature variations are too low to be relevant, so according to these simulations, the solar installation will not have a strong impact on the building thermal comfort conditions.

3.2.2.3 Impact of PV on adjacent rooms and insulation material

The attic zone is not heated during winter, thus only summer conditions will be simulated. The objective is to assess the impact of the solar installation during the hottest week:

- On the indoor air temperature,
- On the outside surface temperature, and on the air gap air temperature.

One must remember that the “Vented cavity” model used is very coarse, as it aims to simulate PV impact at building scale. Assumptions detailed in the previous chapter are coarse, and the results will be less accurate than the ones we get at element level.

Two kinds of hot week can be considered in the analysis:

- the week when outdoor temperature reaches its maximum,

- the week when the “degree day” sum is at its maximum. It represents a week with a succession of hot days.

In the case of the typical climate of Brussels, it happens to be the same week, from the 6th to the 14th of July.

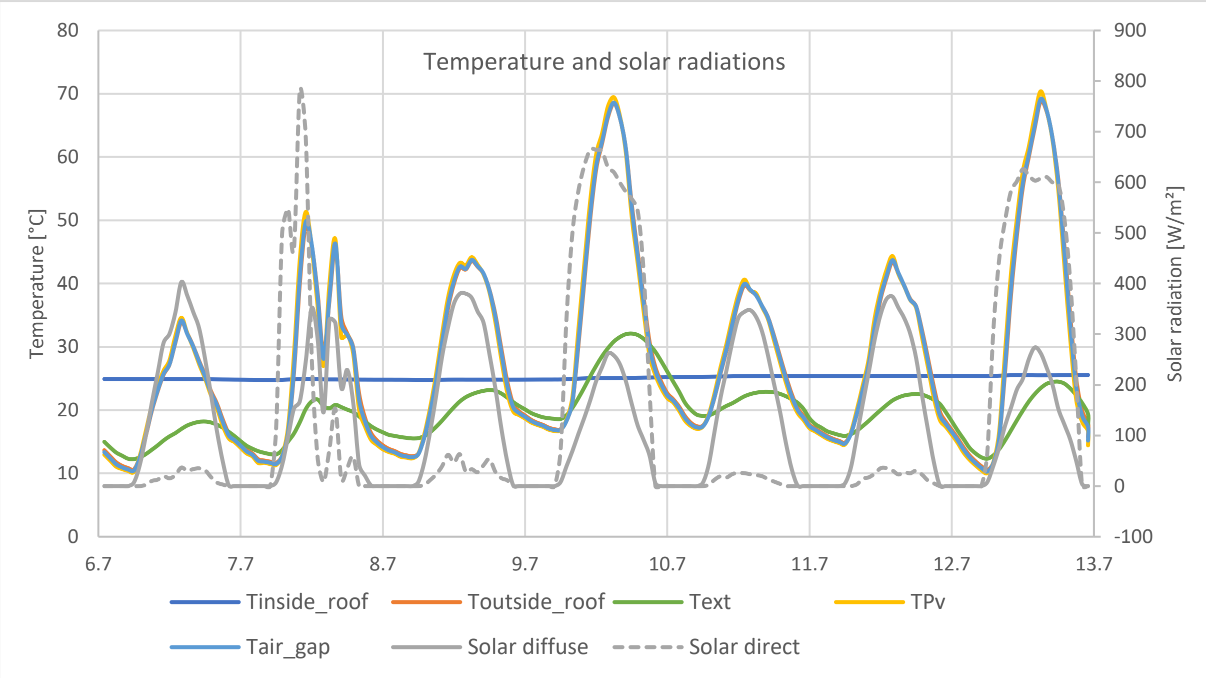


Figure 3.15 DEMO#1 – FD2, Temperature at roof level and solar radiation evolution during the hottest week

The temperature of the attic zone is very close to the roof inside surface temperature (Tinside_roof), so it is not displayed on the above graph. This temperature is almost constant and is very little affected by external conditions. This is due to the absence of heat gain in this zone, and to the 22cm thick insulation.

In this configuration, the PV module temperature, the air gap temperature and the outside surface temperature are nearly equal. Also, their evolution seems to be guided by the amount of solar radiation (grey curves) and not by the external temperature.

In this configuration, the insulation material temperature corresponds to the roof outside surface temperature (Toutside_roof). As displayed on the graph, it is not rising above 70°C which is acceptable. However, this temperature may be linked to the wind and to the buoyancy coefficient selected in the previous chapters. Therefore, simulations have been carried out to take into account the worst case scenarios using low and high values (0.25 to 0.6 for wind coefficient and 0.2 to 0.1 for the buoyancy coefficient). The effect on the cavity air change rate is displayed on the following graph:

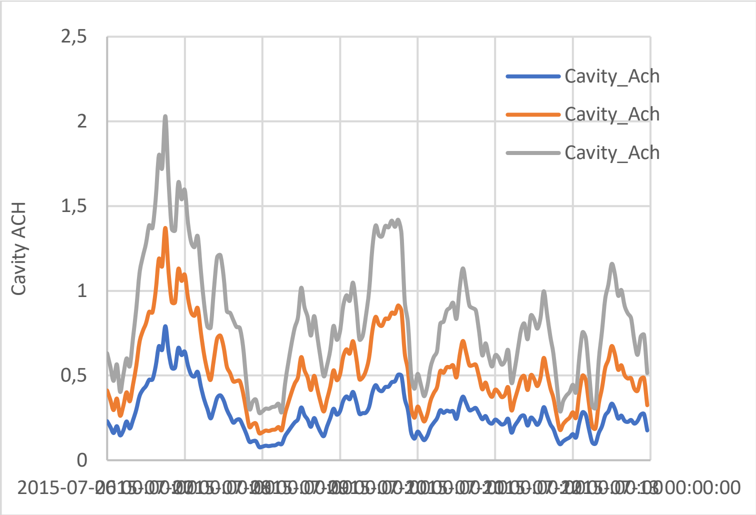


Figure 3.16 DEMO#1 – FD2, Cavity air change rate for various wind and buoyancy coefficients

The results show a great difference in cavity air change rate when considering different buoyant and wind coefficients. For the hottest week, and for low coefficient, the mean ACH is around 0.28 ACH, while it reaches 0.82 ACH for high coefficient. The maximum difference is 1.24ACH.

However, despite this large difference between air flow behaviours, the insulation material temperature is not affected (temperature variations inferior to 1°C). It means that most of the heat transfers between the Solar PV and the insulation material are long wave radiation.

Therefore, the model approximation on the airflow coefficient is not of great importance. However, the simplification made by considering only one emissivity coefficient may affect the results.

Considering these observations, and the little impact on room temperature demonstrated in the previous chapter, more precise simulation at element level will be more suitable to study heat exchanges in the cavity and between solar tiles and roof material.

3.3 Simulation of DEMO#2 – EHG, simulation by ENERGYPLUS

The EHG site (Ecole Hôtelière de Genève) is composed of three buildings housing the hotel school of Genève. It includes classrooms, rooms for student, and administrative offices. It's located Avenue de la Paix 12, 1202, Genève (Switzerland).

3.3.1 Simulation hypothesis

3.3.1.1 Building climate and environment

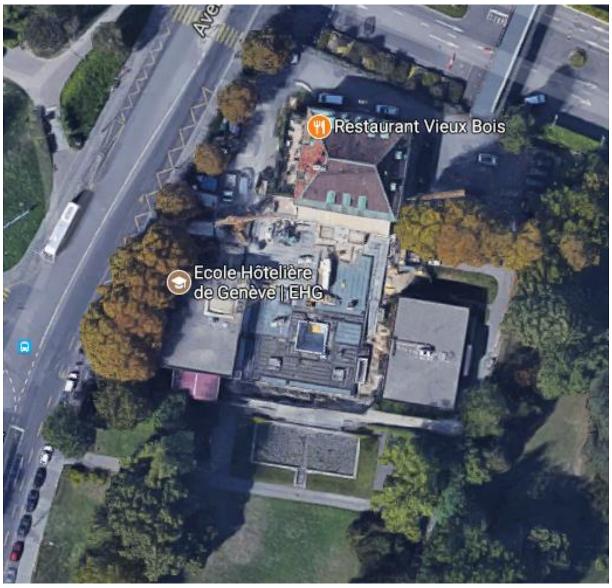


Figure 3.17 Satellite view of the EHG pilot site

The 2 buildings that will host the solar PV are located at the East and at the West on the above figure. Their façades will probably be shaded by the North building (diffuse radiation) and by trees located at the South (diffuse and direct radiation). These masks will be taken into account using opaque and semi-transparent objects.

Considering the location of the school, the climate of the city of Genève has been used for this study. The following graphs gather annual information on temperature and solar radiation level:

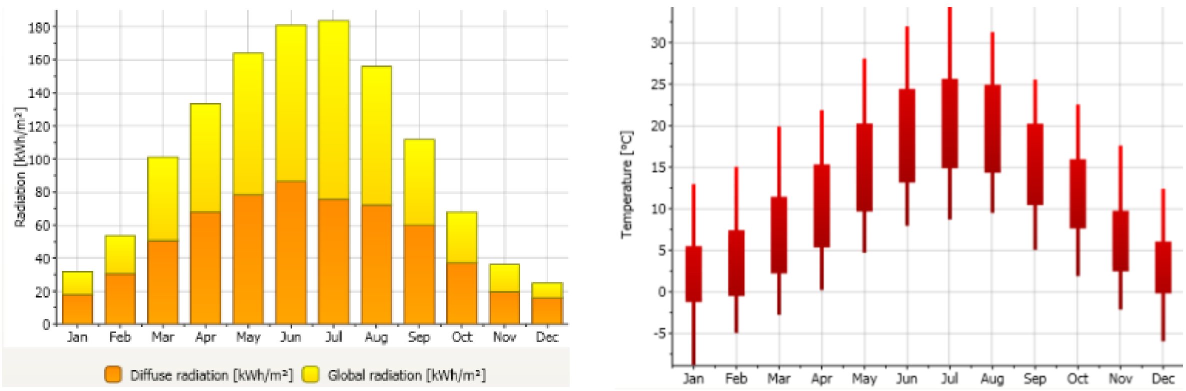


Figure 3.18 Genève - Typical year temperature and radiation profiles

3.3.1.2 Building envelope

Few information are available on buildings envelop for this pilot site. The energy audit document "Audit Energétique Ecole Hôtelière de Genève » written by SIG gives the following information regarding the envelop for the pavilions 1 & 2:

- Walls are made of light brick that gives a light inertia, and are thermally insulated.
- The flat roof is covered with gravel.
- Concerning heat transfer coefficient, the document indicates an overall value of 0.4-0.6 W/m².K for pavilion 1, and 0.2-0.4 W/m².K for pavilion 2. For both buildings, the mean conductivity is considered.

Regarding the openings, double glazing is considered for both pavilions. For pavilion 1 (1980), a 4/6/4 product is considered; the heat transfer coefficient is 3.10 W/m².K. For pavilion 2 (2001), a 4/10/4 double glazing is considered; the heat transfer coefficient is 2 W/m².K. For both buildings, the SHGC is 0.40.

On every façade, the windows are protected by exterior metallic slat blinds to prevent room overheating during summer. The blinds are user controlled; we assume a solar transmission factor of 0.4 and a solar reflectance of 0.4. During the summer, the blinds are down when external temperature reaches 26°C, or when the solar flux on a window is over 126W/m².

No information is available on the infiltration rate. Considering the building construction year (1980 and 2001), the permeability is set to 2.37 Vol/h for a 50Pa pressure drop. According to the EN 13790, it can be modelled as a 0.165 constant Air Change per hour (ACH).

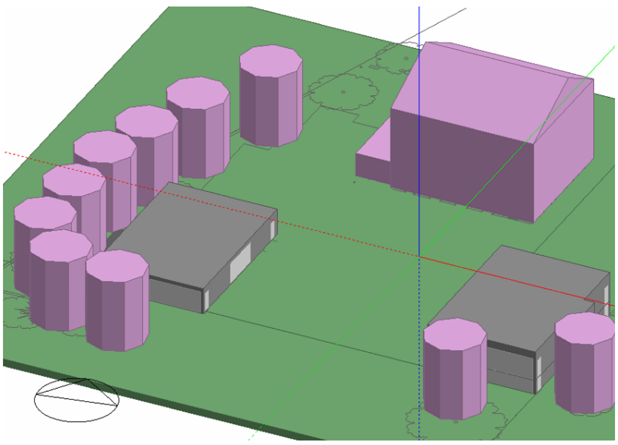


Figure 3.19 DEMO#2 – EHG 3D model view

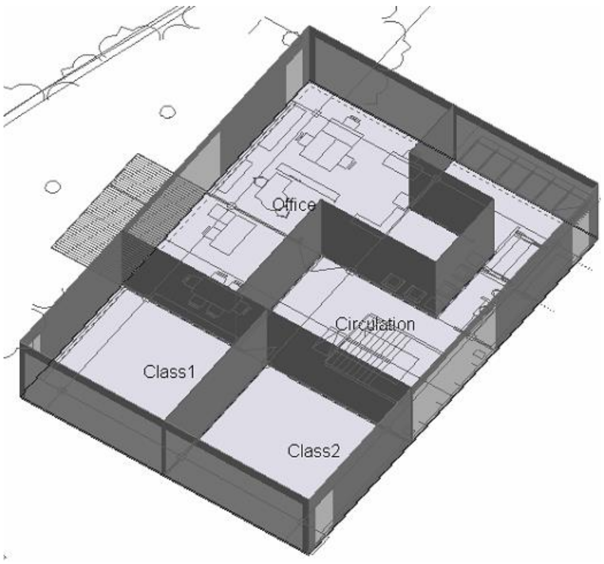


Figure 3.20 DEMO#2 – EHG Pavilion 1 - Ground floor

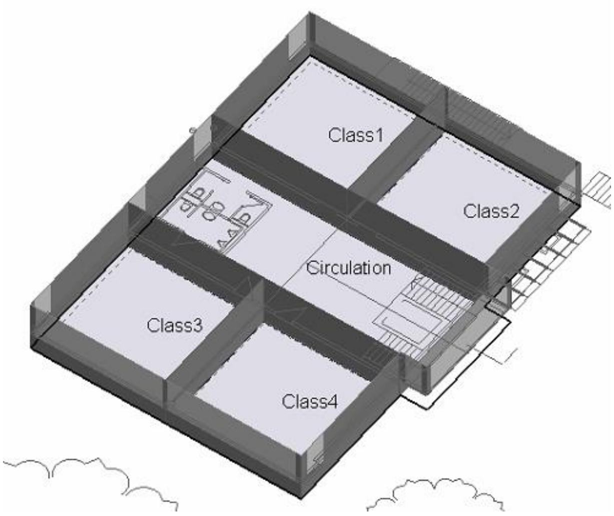


Figure 3.21 DEMO#2 – EHG Pavilion 1 - Ground floor (partially buried)

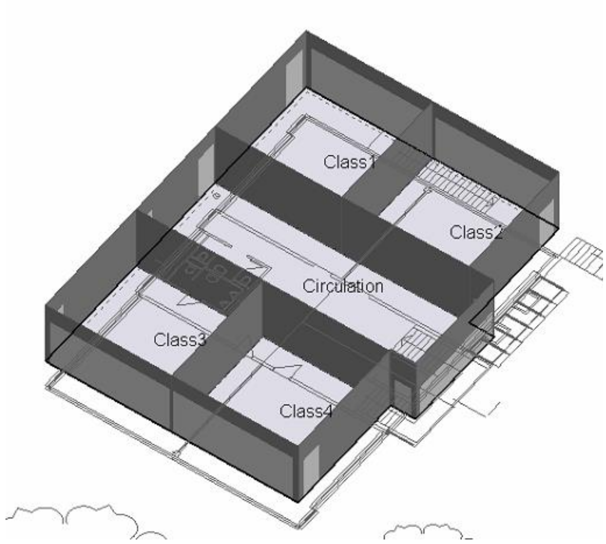


Figure 3.22 DEMO#2 – EHG Pavilion 1 - 1st floor

3.3.1.3 Internal heat gains

The 2 pavilions host classrooms, office spaces and circulation zones. Given that limited information is available, the schedules and the amount of released heat power for the occupancy and the appliances are based on the RT 2012 mandatory calculation in France. It is supposed to represent the "typical" occupation of a French Hostel school [9]:

- The density of people is 0.45 pers/m² for classroom and 0.11 pers/m² for office space,
- For appliances and lighting, a heat gain of 5W/m² is considered.

The considered schedules are shown in the figure below:

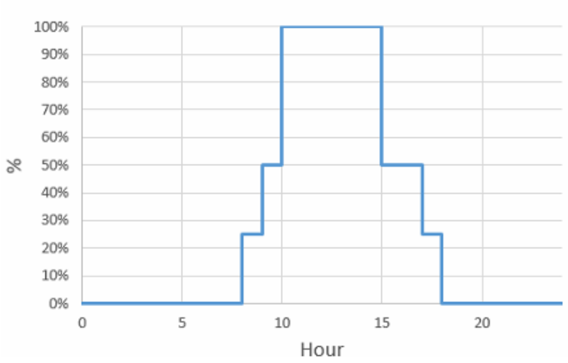


Figure 3.23 DEMO#2 – EHG Occupancy schedule

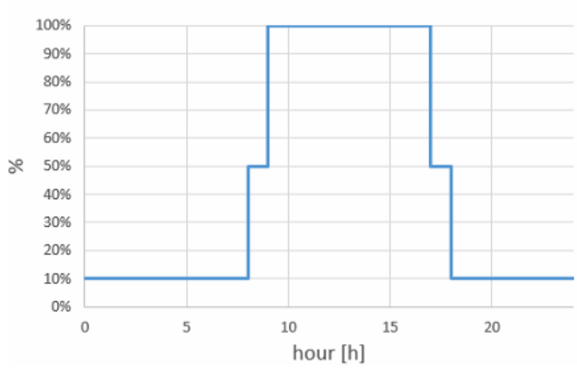


Figure 3.24 DEMO#2 – EHG Appliance schedules

3.3.1.4 HVAC equipment

For HVAC systems, ideal systems are considered.

According to the energy audit document, ventilation is working from Monday to Friday from 7:30 AM to 8:30 PM. Classrooms have a capacity of 25pers; considering a fresh air supply of $18m^3$/h.pers [9], it leads to an air flowrate of $450m^3$ per classroom. For office space, $25m^3$/h.pers is considered [9].

The office parts of buildings are considered to be cooled to a 24°C setpoint from 7:30AM to 8:30PM for every weekday during the summer period. The temperature in the classroom is left uncontrolled.

During the winter, for every weekday, the heating set point is 20°C (energy audit) from 7:30AM to 8:30PM, while the set back is 17°C. During the weekend, the set point is constantly set to 17°C.

3.3.1.5 PV installation

FLISOM PV coverages made with CIGS flexible roofing membrane and bendable elements (model X2 & X4) will be used on this demonstration site. According to the deliverable D8.1, a total surface of $136m^2$ of solar PV modules will be installed for a total power of 12 kWp. 56 modules will be installed on the East façade of pavilion 1 and 99 modules on the West façade of pavilion 2. They will be mounted as cladding system on both walls. The figure below indicates the location for each building.

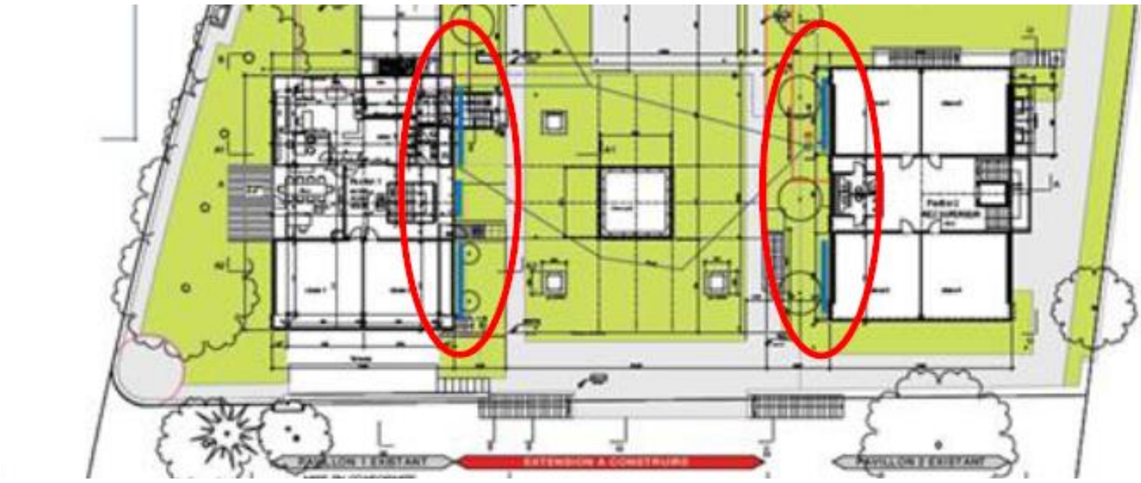


Figure 3.25 DEMO#2 – EHG, FLISOM PV modules location

In EnergyPlus, the installation will be modelled as a naturally vented cavity. The main hypotheses of the model are gathered and explained in the following table:

Table 3.4 PV module model configuration for DEMO#2 – EHG

Internal heat gains		
Area Fraction of Openings [-]	0	The tiles are perfectly adjusted and water proof. There are no openings.
Thermal Emissivity of Exterior Baffle Material [-]	0.84	Measured front side emissivity. Due to model assumption, it corresponds to both front and back side emissivity.
Solar Absorptivity of Exterior Baffle [-]	0.80	According to measurement, the solar absorbance is around 92%. Visible absorbance is 0.95%. Taking into account that around 12% of solar radiations are converted into electricity, it leads to a 0.8 absorbance coefficient.
Effective Thickness of Cavity Behind Exterior Baffle [m]	0.05	According to plans
Roughness of Exterior Surface	Smooth	
Effectiveness for Perforations with Respect to Wind	0.42	These coefficients determine the air change rate of the air gap by buoyant and wind effect. Unfortunately, it is very hard to estimate a value, and most of the time they are determined experimentally. Griffith [3] proposes values ranging from 0.25 to 0.6 for the Cv coefficient and 0.5 for Cd.
Discharge Coefficient for Openings with Respect to Buoyancy Driven Flow	0.5	

3.3.2 Simulation results

3.3.2.1 Impact of PV system on building heat needs

Simulations are carried out over a full year. For heat needs, the results are analysed for the heating period ranging from the 01/01 to the 01/05, and from the 01/10 to the 31/12. The main heat gains and heat losses are aggregated for the whole building and are displayed on the following figure:

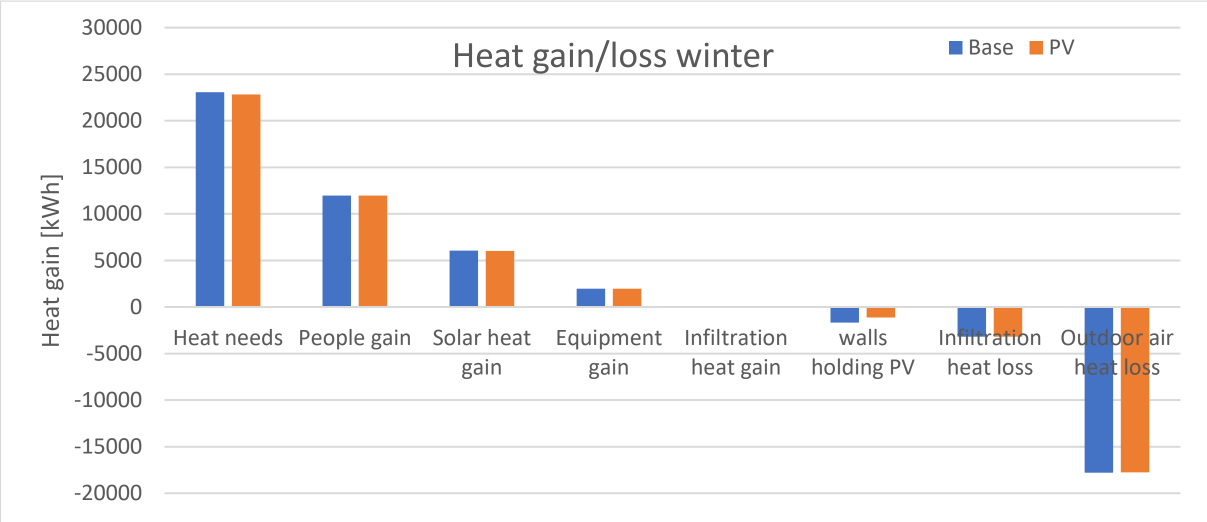


Figure 3.26 DEMO#2 – EHG internal heat gains

According to these results, it can be considered that the PV installation does not affect the overall building heat needs. The difference of energy needs between the buildings performance and the buildings equipped with FLISOM products is around 1%. This is negligible regarding the other approximations made for simulations.

The installation of solar panels impacts the heat transfers by 33% for the concerned surface. However, the heat losses at walls level that sum the convective and radiative heat transfers are very low compared to infiltration or ventilation losses. Moreover, information on actual wall composition are nearly inexistent. Strong hypotheses such as external surface emissivity or solar absorbance for baseline configuration strongly impact this result.

3.3.2.2 Impact of PV system on occupant thermal comfort

Simulations are carried out over a full year. For thermal comfort, the results are analysed for the summer period ranging from the 01/05 to the 30/09. Only the 5 classrooms that will have an external wall equipped with FLISOM product are studied. Below is an example for the classroom located in pavilion 2 R+1. With large openings facing South, it is the “hottest” classroom of the building:

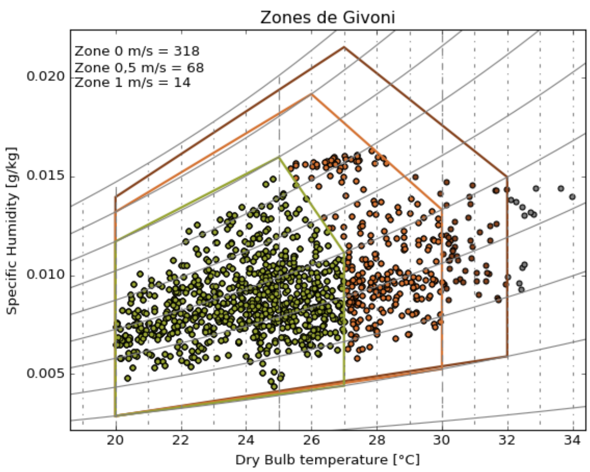


Figure 3.27 DEMO#2 – EHG Pavilion 2 - R+1 class3 BASE

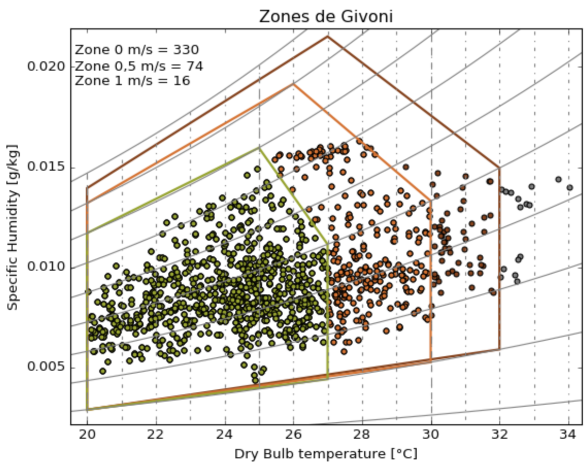


Figure 3.28 DEMO#2 – EHG Pavilion 2 - R+1 class3 PV

The graphics above show a strong risk of discomfort in the classroom. This is mainly due to the internal gains (strong density of students) and to the solar heat gain (large windows facing South in pavilion 1 and 2). Despite of the presence of automated blinds and natural ventilation, the excess of heat cannot be sufficiently removed. It results in a strong risk of overheating.

Two indicators will be used to assess the impact of the solar PV installation on all the main thermal zones:

- The number of hours when the indoor conditions went beyond the first thermal envelop (0 m/s),
- The maximum operative temperature reached.

The table below shows the number of “first envelop overshoot” for each occupied zone with and without the PV installation and the maximum indoor operative temperature:

Table 3.5 EHG internal heat gains

Level	Base Givoni Overshoot	Pv Givoni Overshoot	Maximum impact	Base Maximum temperature	PV Maximum temperature	Maximum temperature delta
Pavilion 1 Class2	307	313	2%	33.8	34.0	0.24
Pavilion 2 R+1 Class1	269	278	3%	34.3	34.5	0.18
Pavilion 2 R+1 Class3	318	330	4%	34.3	34.5	0.18
Pavilion 2 RDC Class1	254	261	3%	32.6	32.7	0.14
Pavilion 2 RDC Class3	315	328	4%	32.6	32.7	0.15

Considering these results, the solar installation won’t have a strong impact on the rooms located at the ground floor.

For the classrooms, the number of hours the indoor conditions overshoot Givoni first envelope doesn’t increase by more than 4%. Moreover, maximum temperatures in these rooms do not increase by more than 0.24°C.

These temperature variations are too low to have a noticeable impact; so according to these simulations, the solar installation will have a negligible impact on the building thermal comfort conditions.

3.3.2.3 Impact of PV on adjacent rooms and insulation material

Two zones are studied: the classroom 2 located in pavilion 1 with windows facing South, and classroom 1 located in pavilion 2 at the 1st floor with main windows facing North. The detailed analysis of these 2 rooms will allow us to evaluate the impact of PV system depending on building envelop performance and considering a different amount of heat gain. The objective is to assess the impact of the solar installation during two “extreme” weeks in a year (hottest and coldest weeks):

- On the indoor air temperature,
- On the outside surface temperature, and on the air gap temperature.

One must remember that the “Vented cavity” model used is very coarse, as it aims to simulate PV impact at building scale. The assumptions detailed in the previous chapter are coarse, and the results will be less accurate than the ones we get at element level.

3.3.2.3.1 Hottest week results

The following figures display the temperatures and solar radiation evolutions during the hottest week for both PV installations.

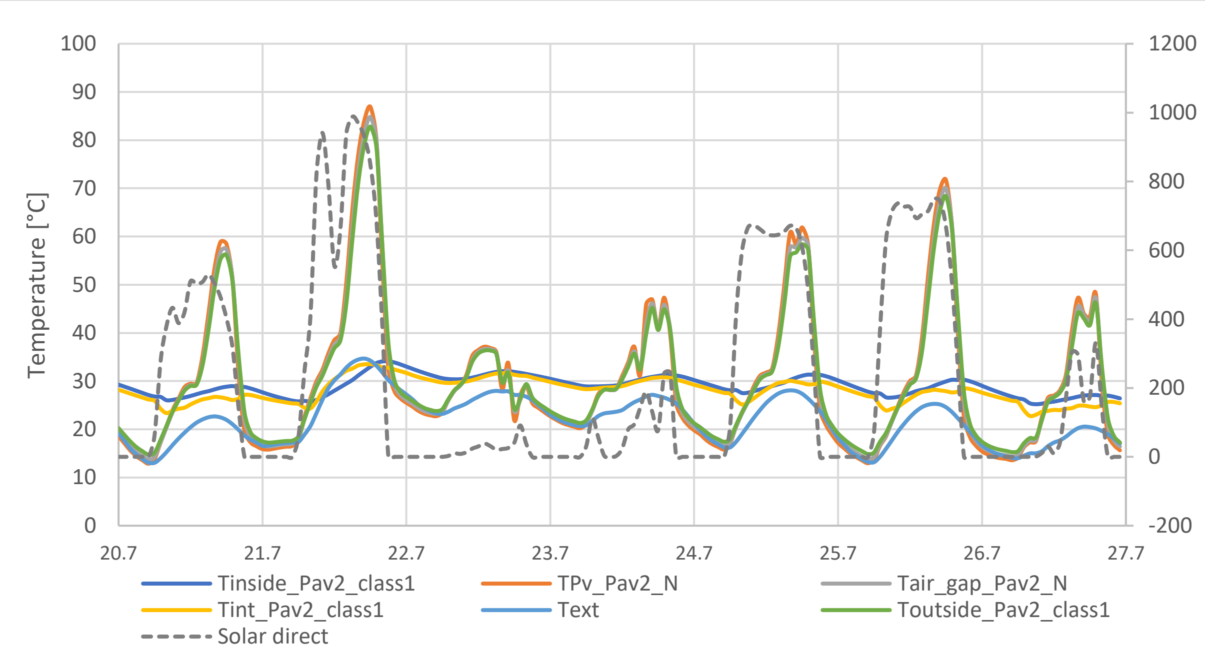


Figure 3.29 DEMO#2 – EHG Temperatures and solar radiation evolution during the hottest week for PV facing West

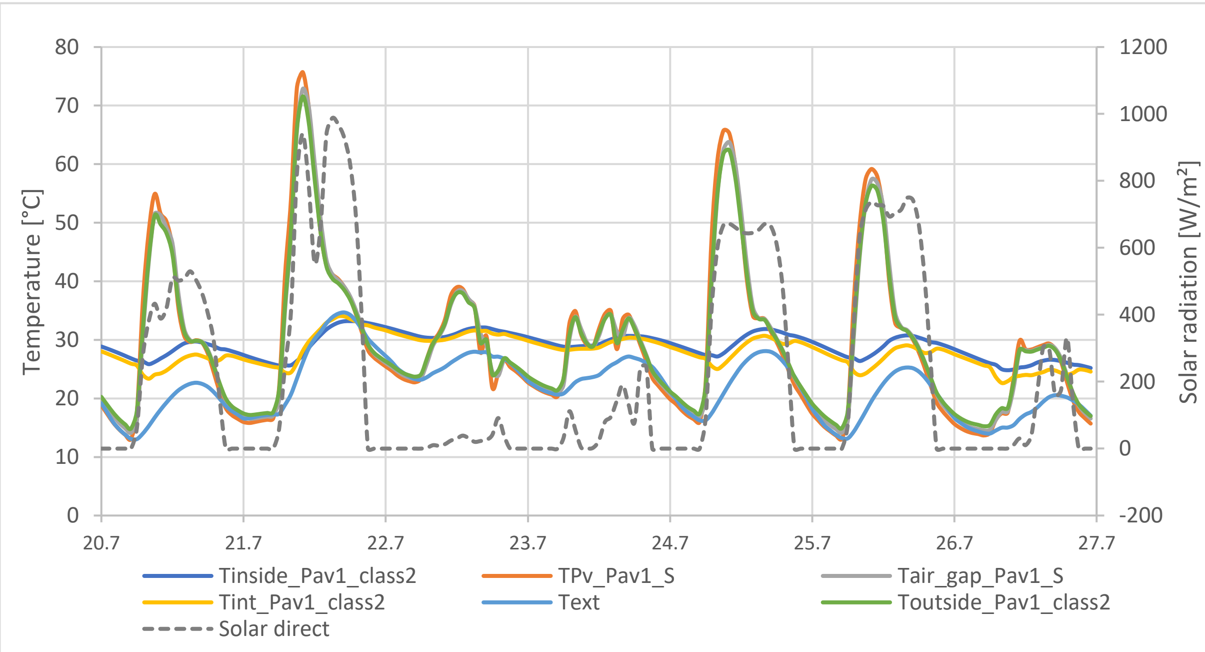


Figure 3.30 DEMO#2 – EHG Temperatures and solar radiation evolution during the hottest week for PV facing East

For both PV installations, temperature of the modules, temperature of the air in the cavity, and temperature at the external face of the wall are very close. The temperature is mainly guided by the amount of direct solar radiation. For both orientations, the peak of temperature happens at the beginning or at the end of the day, depending on the PV orientation.

For both classrooms, inside air temperature and internal face wall temperature are nearly equal. Cavity temperature doesn't seem to strongly affect indoor temperature.

Whatever the orientation, PV temperature does not exceed 90°C. As for the FD2 demo site, this value should not be much affected by the buoyant and wind coefficient hypothesis. The air gap ACH is variable depending on the wind speed and solar radiation. They are displayed on the graphic below:

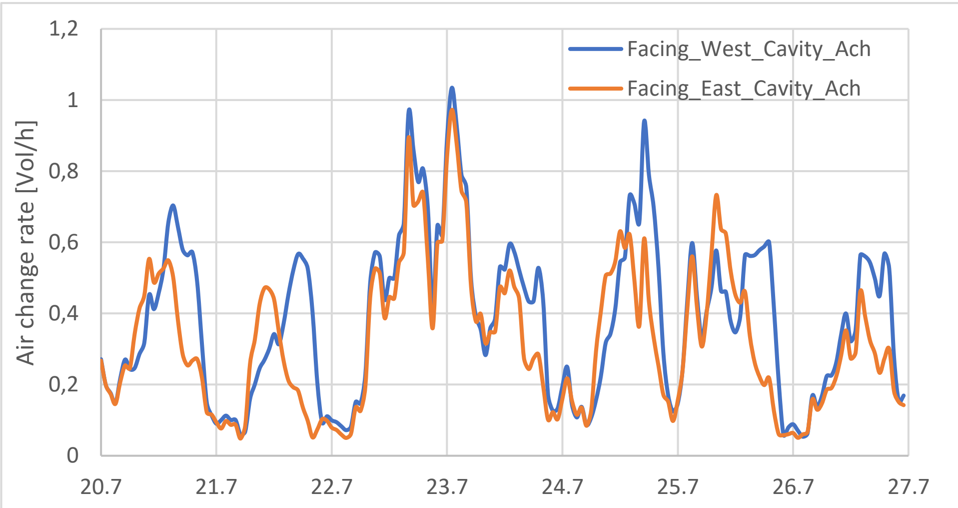


Figure 3.31 DEMO#2 – EHG Cavities air change rate

3.3.2.3.2 Coldest week result

The following figures display the temperatures and solar radiation evolutions during the coldest week for both PV installations.

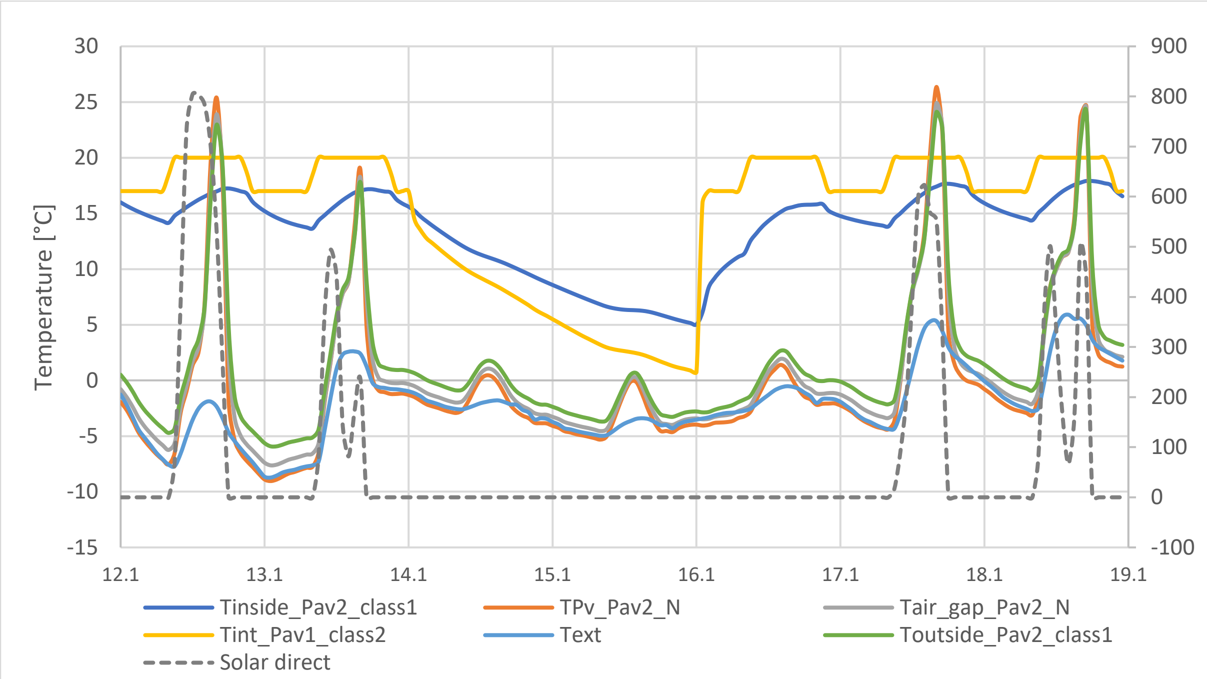


Figure 3.32 DEMO#2 – EHG Temperatures and solar radiation evolution during the coldest week for PV facing West

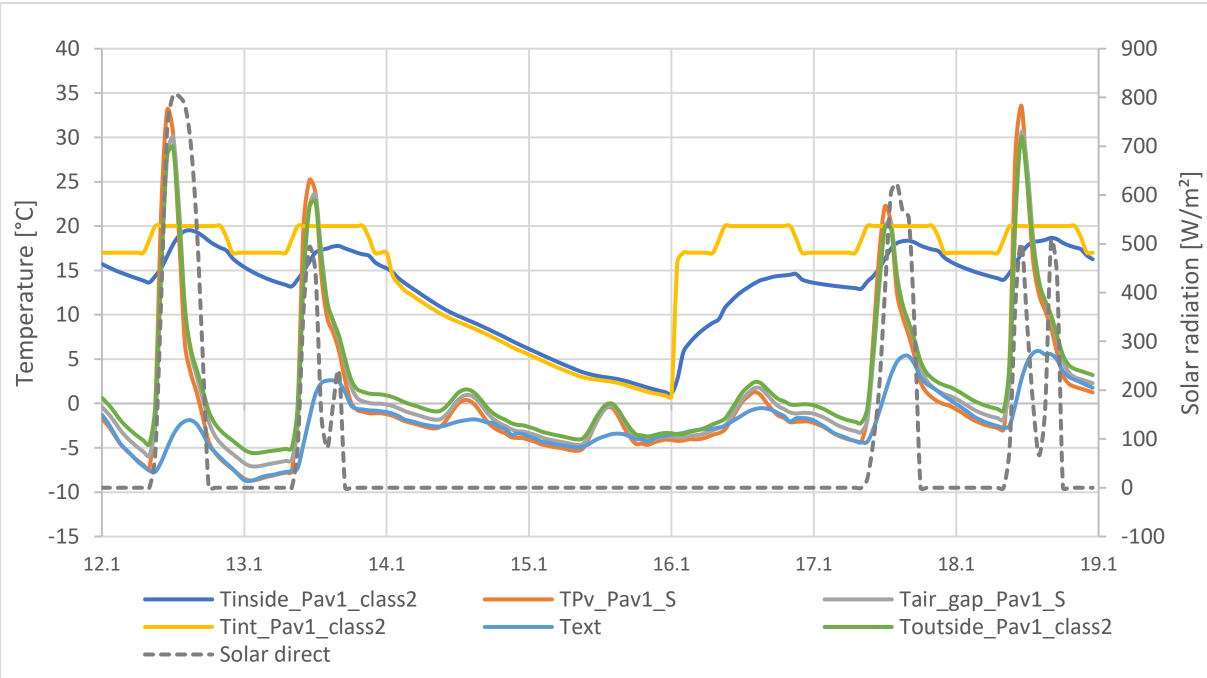


Figure 3.33 DEMO#2 – EHG Temperatures and solar radiation evolution during the coldest week for PV facing east

For both PV installations, temperature of the modules, temperature of the air in the cavity, and temperature at the external face of the wall are very close. Even during cold days, temperature is still mainly guided by the amount of direct solar radiation. It can be seen that during the 2 days when there is no direct solar radiation, the module temperature is slightly rising at the middle of the day due to the amount of diffuse radiation. Otherwise, for both orientations, peak of temperature still happens at the beginning or at the end of the day, depending on the PV orientation.

For both classrooms, a temperature gradient exists between indoor air temperature and internal face wall temperature. This may affect occupant thermal comfort as long wave energy transfer happens. However, previous chapters showed that energy needs remain unchanged; thus, the installation of BIPV module should not imply a significant difference in occupant thermal comfort.

3.4 DEMO#3 – CARPORT of EMPA facilities

This demonstration site is not a building but a car parking area. No simulation can be performed for this typology of building.

3.5 DEMO#4 – CRICURSA building, simulation by ENERGYPLUS

FLISOM CIGS on metal BIPV products are planned to be installed on the building of CRICURSA located in Spain. This demonstration site is a large hangar that houses industrial machinery (such as ovens).

This equipment rejects a large amount of thermal energy into their environment.

The air change of the building is handled by roof air extractors.

Given the nature of the building and its industrial activity, a “classic” building thermal simulation is not adapted. Indeed:

- Considering the large dimensions of the modeled zone the assumption of a uniform temperature is not suitable nor valid.
- The amount of heat gain released by the equipment and the schedules are unknown and largely variable.
- The amount of air extracted by the roof fans is unknown.

Considering this information, the approximations that have to be done to build the model completely override the effect of the solar panels on the building consumption.

Indeed, in this case, the BIPV system only alters the amount of radiation that is transmitted to the building. Yet this amount of energy is extremely low compared to the equipment heat gain, or compared to the energy extracted by the roof fan.

Therefore, it is proposed not to simulate this demonstration site, in order to focus more in detail on EHG and FD2 demo site that feature the same BIPV products.

3.6 DEMO#5 – Vilogia building, simulation by ENERGYPLUS

The Vilogia demonstration site is located close to Lille (France) (12-14, rue du Docteur Laennec, Wattignies, 59139, France). It is a 3639m² residential building with 7 identical floors plus a ground floor. The solar panels are planned to be installed on the vertical South façade of the building.

3.6.1 Simulation hypothesis

3.6.1.1 Building climate and environment

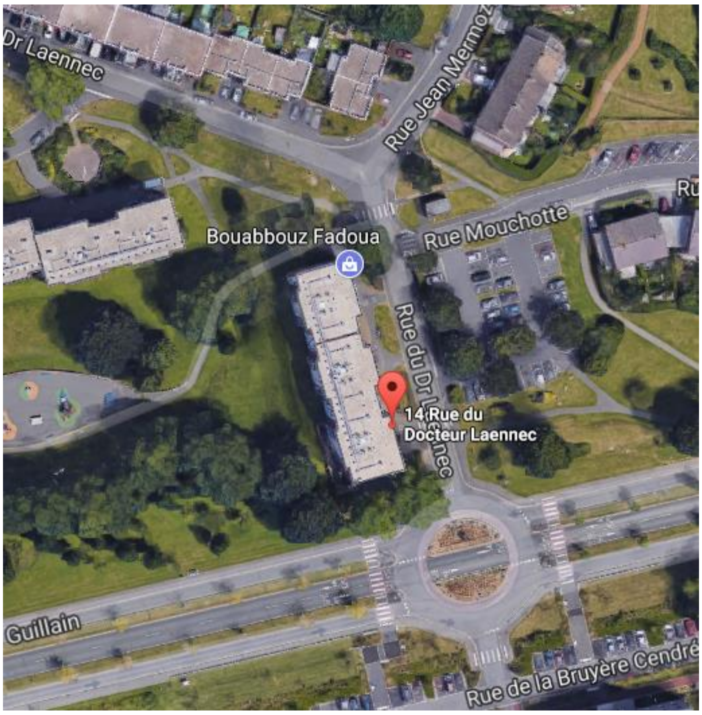


Figure 3.34 Satellite view of the Vilogia building

Similarly, to the FD2 house, two trees may cast shadows on the South facade. However, as no information on their size or their height are available they won't be modelled. On a thermal point of view, and regarding the objectives of Task 8.1, this approximation will not affect the comparison between the different simulations performed, nor the conclusions.

Considering the location of the building, the climate of the city of Lille has been used for this study. The following graphs gather annual information on temperature and solar radiation level:

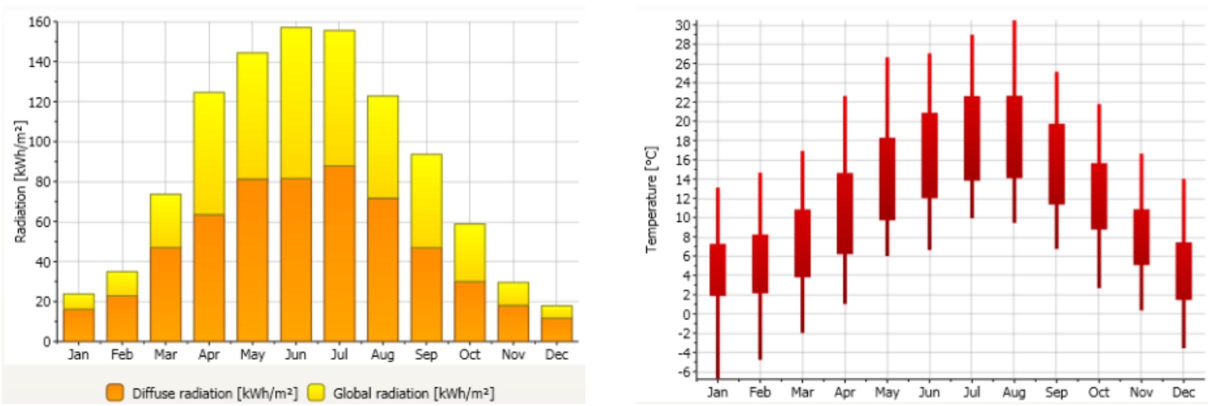


Figure 3.35 Lille - Typical year temperature and radiation profiles

3.6.1.2 Building envelope

Building envelop hypotheses have been extracted from the mandatory French simulation (RT 2012):

- Despite a previous retrofit, the insulation of the building is very poor. Walls heat transfer coefficient is ranging from 2.17 W/m².K for non-insulated façade to 0.224 W/m².K. Cold bridges have been taken into account as additional losses.
- Windows Solar Heat Gain Coefficient is considered to be 0.50, overall heat transfer coefficient y (including frame) is 4.20 W/m².K.
- No infiltration measurement has been made. Given the age of the building they have been estimated to 1.75 m^3/h.m² for 50 Pa pressure drop. According to the EN 832, it can be modelled as a 0.319 constant ACH.

Concerning the thermal zone, for computational time, only 3 floors of the building have been modelled in a detailed way: the ground floor, the 4th and the 7th floors. Each floor is divided in 6 thermal zones. 3 of them model the circulations between the flats, the 3 other thermal zones model the North-oriented flat, the 4 middle flats and the South-oriented flat.

This particular thermal zones separation allows us to study the heat needs of the flats depending on their orientation, or their outside "boundary condition" (exterior or PV installation).

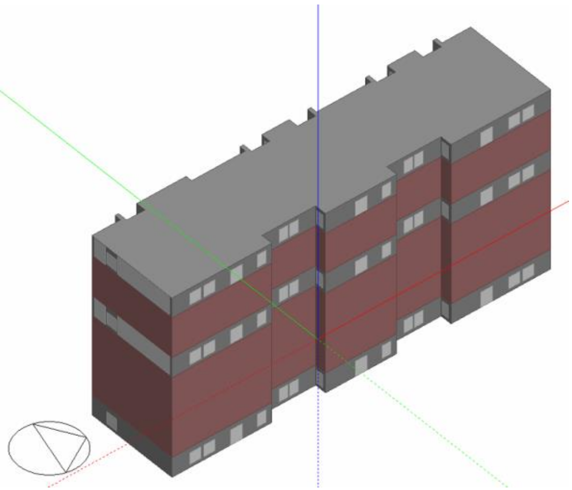


Figure 3.36 DEMO#5 – Vilogia 3D model view

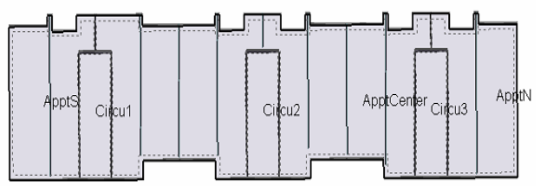


Figure 3.37 DEMO#5 – Vilogia Ground level_Thermal Zones

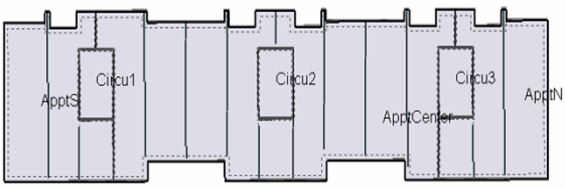


Figure 3.38 DEMO#5 – Vilogia R+1_Thermal Zones

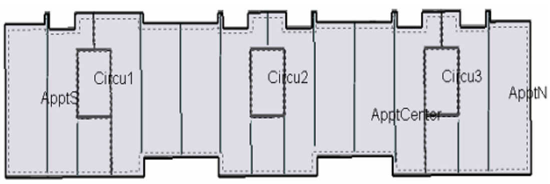


Figure 3.39 DEMO#5 – Vilogia R+2_Thermal Zones

3.6.1.3 Internal heat gains

The apartments hold 2 to 3 bedrooms, a living room, a kitchen and a bathroom.

- 3 to 4 people are considered occupying the apartment depending on the size. This leads to consider a density of 0.042 pers/m². A metabolic rate of 100W/pers is considered. The schedules for the occupation is based on the RT 2012 mandatory calculation in France. It is supposed to represent the “typical” occupancy of a French residential building [9].
- Considering the appliances heat gain, the RT 2012 values and schedules have also been considered. The heat gain is 5.7W/m² with a radiant fraction of 0.2. The schedules are detailed below:

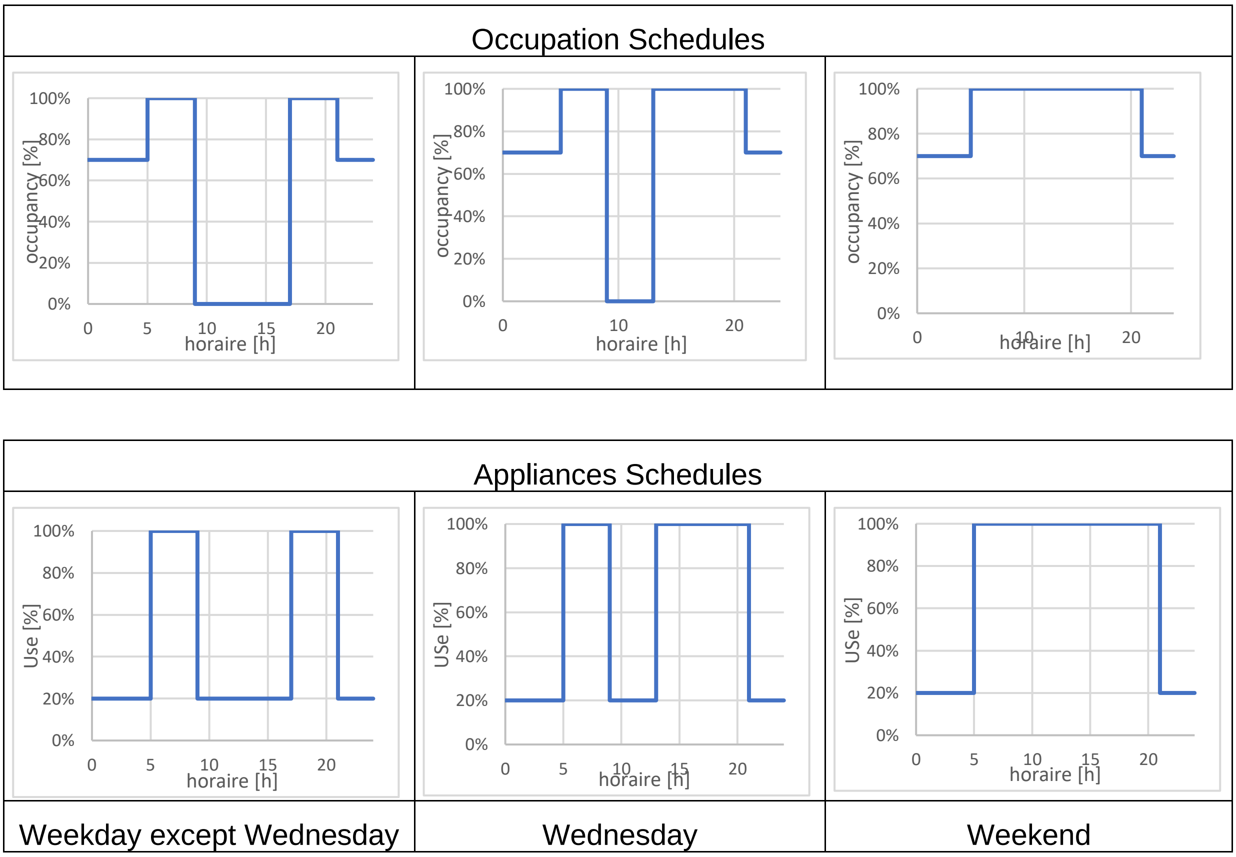


Figure 3.40 DEMO#5 – Vilogia RT2012 occupancy and appliance schedules

3.6.1.4 HVAC equipment

Concerning HVAC equipment, the hypothesis is also taken from the RT 2012 calculation. Ideal systems are considered; HVAC systems properties (efficiency, regulation, inertia) are not modelled.

The building doesn’t have any cooling equipment. During the winter, for every day weekday, the heating set point is 19°C from 8:00 AM to 21:00, while the set back is 16°C. During the weekend, the set point is constantly set to 19°C.

Concerning the ventilation system, the mandatory air flow rate for residential building has been considered [10]:

Table 3.6 Air flow rate computed on French recommendation

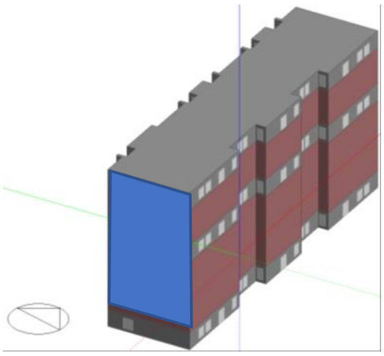
Number of rooms	Kitchen [m³/h]	Bathroom [m³/h]	Toilets [m³/h]	Total [m³/h]
4	120	30	30	180
5	135	30	30	195

The mechanical ventilation system is humidity sensitive. The air flow rate is at its maximum when occupants are present in the dwellings. The schedule for the ventilation system is similar to the one used for the occupancy.

3.6.1.5 PV installation

This demo site will be equipped with ONYX fully opaque glass-glass BIPV (model X5). They use a c-SI technology with hidden conductive ribbons over welded cells that give a uniform appearance. According to the document D8.1, the most relevant location for the BIPV is the building South façade. The orientation, the available space, and the absence of mask make it the optimal placement.

A total of 173m² will be installed for a total of 102 modules and with an overall power of 26kWp. The installation will cover the south wall from the 1st to the 7th floor according to the figure below:



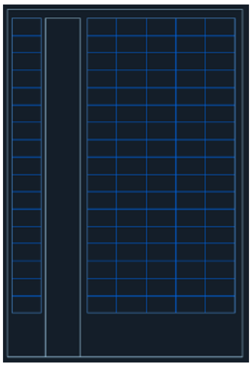


Figure 3.41 ONYX model X5 PV modules location

In EnergyPlus, the installation will be modelled as a naturally vented cavity. The main hypotheses of the model are gathered and explained in the following table:

Table 3.7 Vilogia PV module model configuration

Internal heat gains		
Area Fraction of Openings [-]	0	The tiles are perfectly adjusted and water proof. There are no openings.
Thermal Emissivity of Exterior Baffle Material [-]	0.839	From measurement.(TECNALIA)
Solar Absorptivity of Exterior Baffle [-]	0.80	According to measurement, the solar absorbance is around 92%. Visible absorbance is 0.95%. Taking into account that around 12% of solar radiations are converted into electricity, it leads to a 0.8 absorbance coefficient.
Effective Thickness of Cavity Behind Exterior Baffle [m]	0.05	According to plans
Roughness of Exterior Surface	Smooth	
Effectiveness for Perforations with Respect to Wind	0.42	These coefficients determine the air change rate of the air gap by buoyant and wind effect. Unfortunately, it is very hard to estimate a value, and most of the time they are determined experimentally. Griffith [3] proposes values ranging from 0.25 to 0.6 for the Cv coefficient and 0.5 for Cd.
Discharge Coefficient for Openings with Respect to Buoyancy Driven Flow	0.5	

3.6.2 Simulation results

3.6.2.1 Impact of PV system on building heat needs

Simulations are carried out over a full year. For heat needs, the results are analysed for the heating period ranging from the 01/01 to the 01/05, and from the 01/10 to the 31/12. The main heat gains and heat losses are aggregated for the whole building. The results of the 4th floor are multiplied by 6 to take into account non simulated floors. The results are displayed on the following figure:

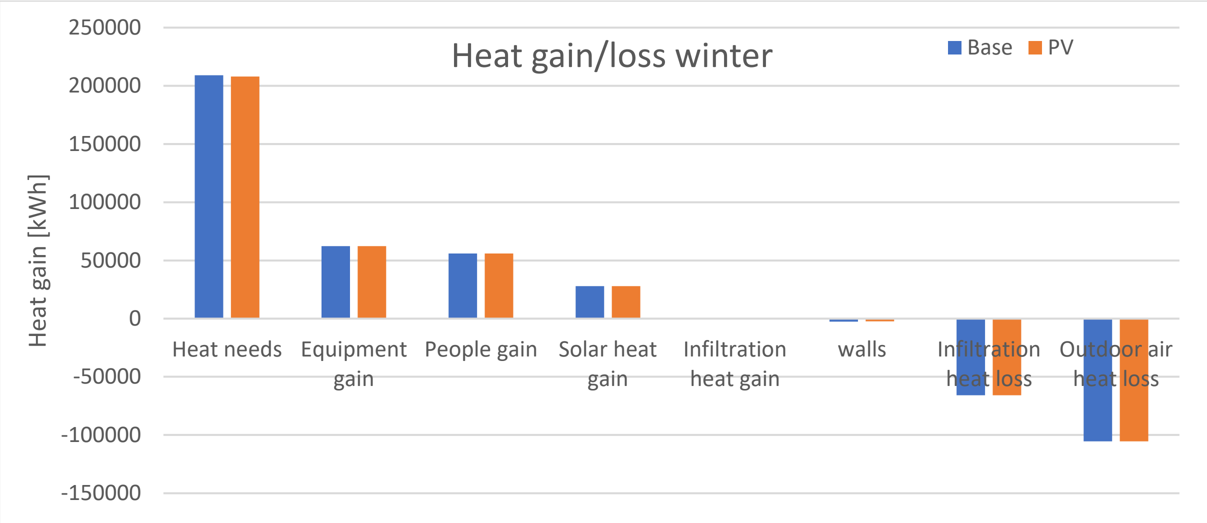


Figure 3.42 DEMO#5 – Vilogia internal heat gains

According to these results, it can be considered that the PV installation does not affect the overall building heat needs. The difference of heat needs between the buildings performance and the buildings equipped with ONYX products is less than 1%. This is negligible regarding the other approximations made for simulations.

The installation of solar panels impacts the heat transfers by only 17% for the concerned surface.

3.6.2.2 Impact of PV system on occupant thermal comfort

Simulations are carried out over a full year. For thermal comfort, the results are analysed for the summer period ranging from the 01/05 to the 30/09. The results focus on the 2 apartments that will have an external wall equipped with ONYX products and that are simulated (4th and 7th floors). Below is the graphic representation of Givoni thermal zone for the 4th floor south apartment (the most impacted by the BIPV solution) :

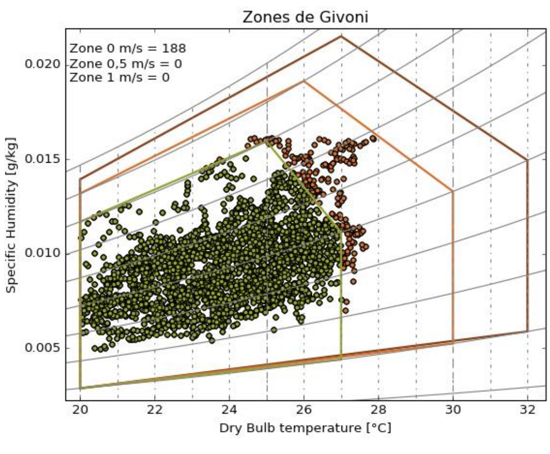


Figure 3.43 DEMO#5 – Vilogia Pavilion 2 - R+1 class3 BASE

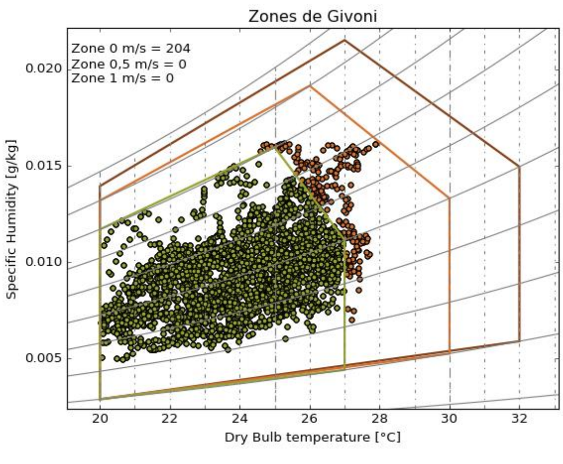


Figure 3.44 DEMO#5 – Vilogia Pavilion 2 - R+1 class3 PV

The graphics above show a small to no risk of thermal discomfort in the apartment. This is mainly due to the strong inertia of the building (concrete structure) and to the small windows to wall ratio that limits the amount of solar heat gains.

The table below shows the number of "first envelop overshoot" for each occupied zone with and without the PV installation and the maximum indoor operative temperature:

Table 3.8 DEMO#5 – Vilogia, Internal heat gains

Level	Base Givoni Overshoot	Pv Givoni Overshoot	Maximum impact	Base Maximum temperature	Pv Maximum temperature	Maximum temperature delta
R4:ApptS	188	204	8%	27.9	27.9	0.02
R7:ApptS	71	74	4%	26.2	26.2	0.04

Considering these results, the solar installation will have nearly no impact on the apartments summer thermal comfort. The variations are too low to have a relevant impact on the indicators.

3.6.2.3 Impact of PV on adjacent rooms and insulation material

The studied zone is the apartment facing South located at the 4th floor. The following figures display the simulation results for the hottest week of the year.

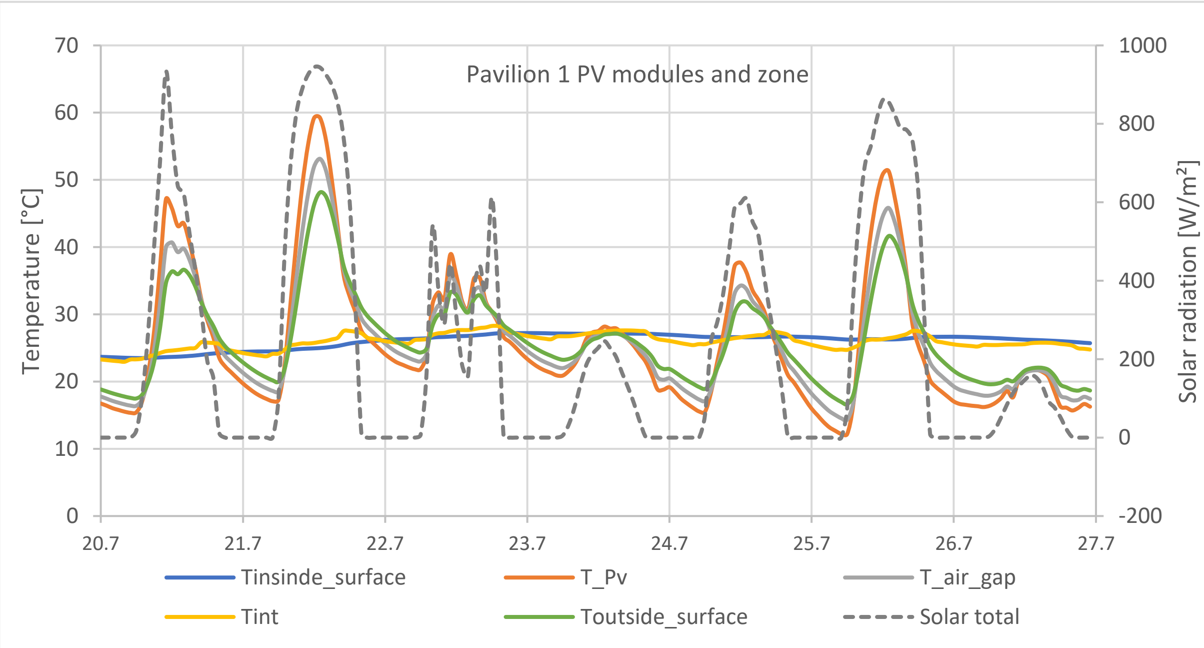


Figure 3.45 DEMO#5 – Vilogia, Temperatures and solar radiation evolution during the hottest week for PV and room facing South

Unlike the previous demonstration sites, a temperature difference can be observed between the BIPV temperature, the air gap and the wall outside surface temperature. The figure shows that the temperature profile is still guided by the amount of radiation received by the modules. But the temperature difference is mainly due to the convection in the airgap. Due to the height of the cladding, a strong buoyant effect induces a high air flow rate. It also leads to a much lower PV panel temperature (60°C) which should increase PV efficiency compared to the other demonstration sites.

Similarly to the other demonstration sites equipped with opaque BIPV, inside air temperature and internal face wall temperature are nearly equal. Cavity temperature doesn't seem to strongly affect indoor temperature.

The following figure displays the air gap air change rate and the air flow ate induced by wind and buoyant effect:

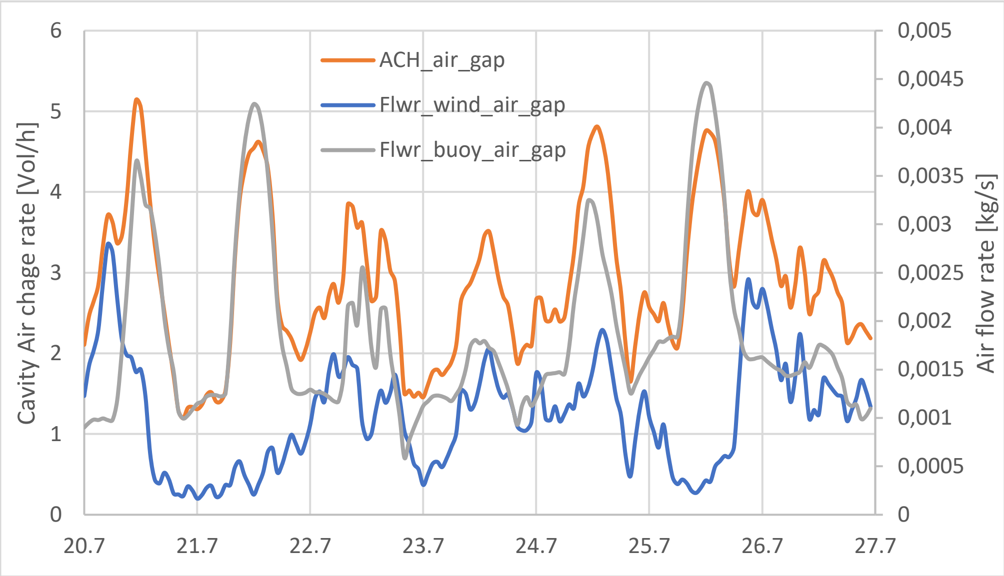


Figure 3.46 DEMO#5 – Vilogia, Temperatures and solar radiation evolution during the hottest week for PV facing South

3.7 DEMO#6 – TECNALIA building, simulation by ENERGYPLUS

3.7.1 Simulation hypothesis

Tecnalia demonstration site is located in San Sebastian (Paseo Mikeletegi 2, Spain). It’s a 14m high building, housing both office spaces and a chemical laboratory. The ONYX semi-transparent BIPV panels are planned to be installed on the South façade of the building. They will face the curtain wall on the second and on the third floors of the building.

3.7.1.1 Building climate and environment

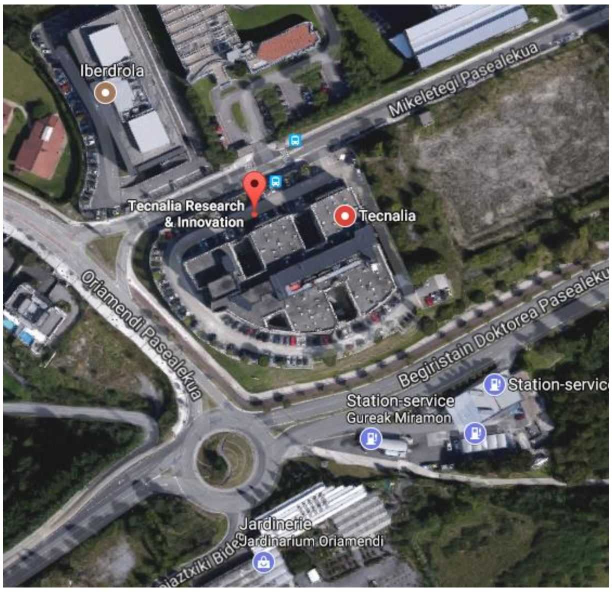


Figure 3.47 Satellite view of the TECNALIA building

On this demonstration site, the neighbour buildings are far enough so no solar masks will affect the BIPV systems. Considering the location of the building, the climate of the city of San Sebastian has been used for this study. The following graphs gather annual information on temperature and solar radiation level:

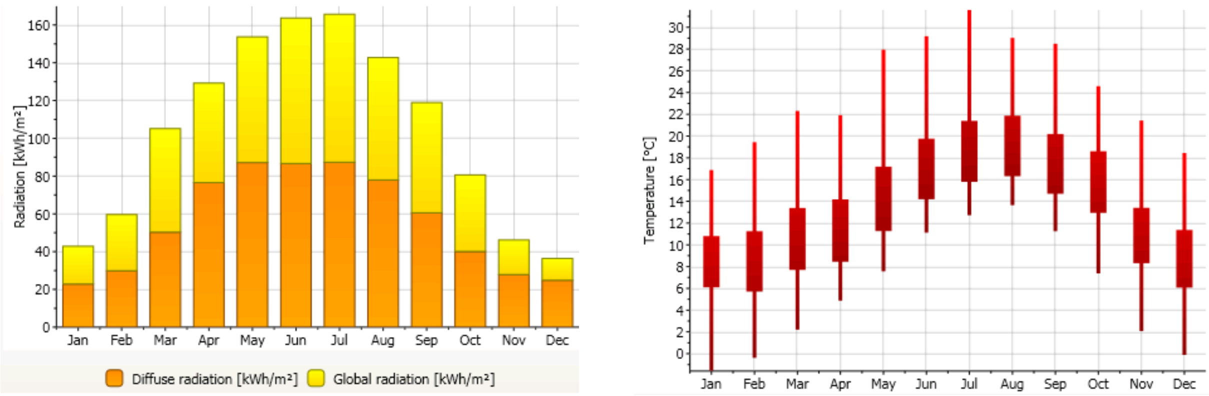


Figure 3.48 San Sebastian - Typical year temperature and radiation profiles

3.7.1.2 Building envelope

Several hypotheses have been made to define the envelope performance. On the other hand, given that only a part of the floor is modelled, the only heat transfer to the exterior occurs through the external walls and through the curtain walls:

- The wall layer composition is derived from the ASHRAE value; it's a non-structural light wall made of plaster and insulation material. The heat transfer coefficient is 0.361 W/m².K. Internal floor and partition have been considered and contribute to the internal heat capacity.
- Measurements have been performed on external windows. The windows SHGC is considered to be 0.75; overall heat transfer coefficient (including frame) is 4.20 W/m².K.
- No infiltration measurement has been made. Given the age of the building they have been estimated to 0.65 m^3/h.m² for 50 Pa pressure drop. According to the EN 832, it can be modelled as a 0.119 constant ACH.

Solar panels are positioned in front of the curtain walls on the 2nd and 3rd floors. The changes in solar radiation and heat transfer will mostly affect the adjacent zones. Thus only one floor with few office space is modelled and only a part of the large open space at the centre of the building is considered. The internal boundary conditions are considered adiabatic.

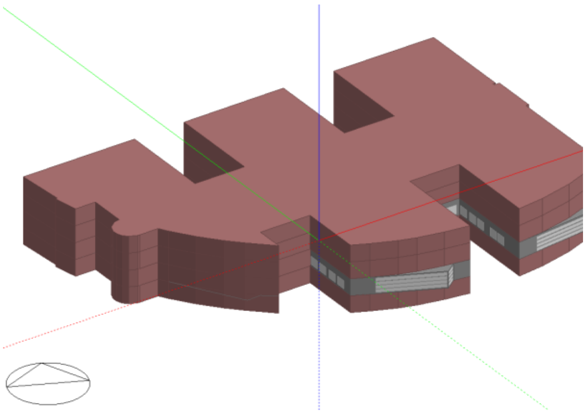


Figure 3.49 DEMO#6 – TECNALIA, 3D model view

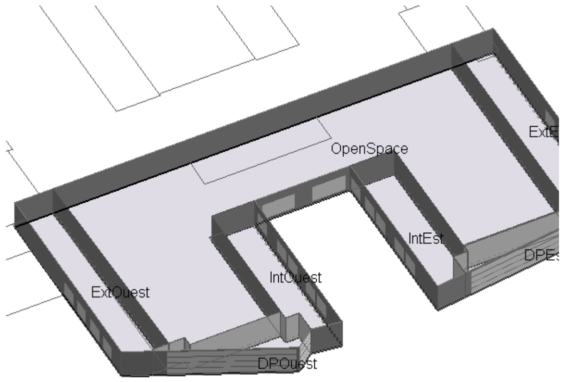


Figure 3.50 DEMO#6 – TECNALIA, Ground floor_Thermal Zones

3.7.1.3 Internal heat gains

The model includes 5 office spaces. The two thermal zones located behind the curtain wall are considered empty.

- The number of workstations per zone has been used to determine the amount of person. It leads to a density between 0.06 and 0.08 pers/m². A metabolic rate of 100W/pers is considered. The schedules for the occupancy is given by TECNALIA. 100% of the worker are considered present from Monday to Thursday: 8:30-13:45; 14:45-18:00. Friday 8:30-15:00.
- Concerning appliances, a heat gain of 1.5W/m² to 2.0W/m² is considered, corresponding to laptops and screens use. The occupation schedule is also considered.
- Concerning lighting use, a 5W/m² heat gain is taken into account. According to TECNALIA, it is turned on every weekday from 8AM to 5PM.

3.7.1.4 HVAC equipment

Ideal HVAC systems are considered.

The building is being cooled to a 24°C setpoint from 8AM to 5PM for every weekday during the summer period. During the winter, for every weekday, the heating set point is 21°C from 8AM to 5PM, while the set back is 17°C. During the weekend, the set point is constantly set to 17°C.

Concerning the ventilation system, the French mandatory air flow rate of 25m^3/pers is considered. Ventilation system is turned on between 8AM and 5PM every weekday. A 15% efficient heat exchanger is considered.

3.7.1.5 PV installation

ONYX X6 glass-glass products with back contact c-Si cells have been selected for this demonstration site. Three configurations are compared to assess the impacts of the modules:

- The baseline configuration is the actual TECNALIA building without the modules,
- The 72 modules configuration that is described in the deliverable D8.2. The system power is 14.9 kWp for a total module surface of 103.5m²
- The 96 modules configuration that has been selected for the project. This configuration leaves no free space between the modules. The system power is 19.8 kWp for a total module surface of 132 m²

Modules will be held by a mechanical structure and mounted in front of the curtain wall. In EnergyPlus, the installation will be modelled as an external shading system.

Figure 3.51 Panels configuration for TECNALIA building

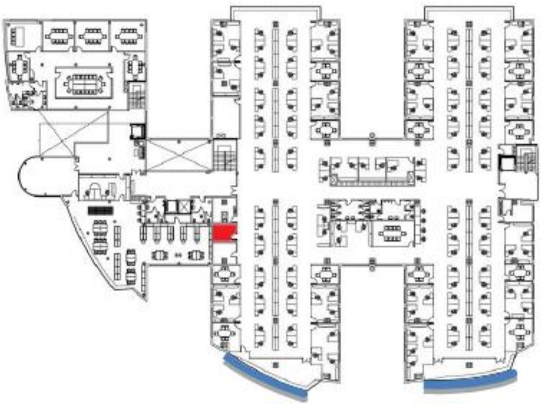


Figure 3.52 Panels location for TECNALIA building

3.7.2 Simulation results

3.7.2.1 Impact on natural lighting level

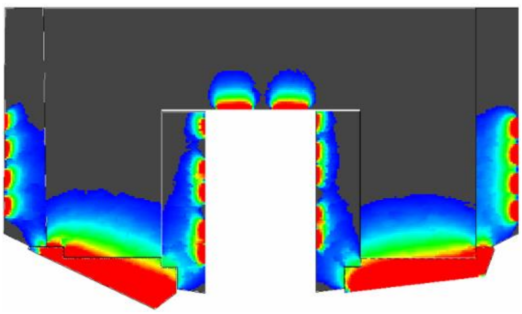
As for UV solar radiation, visible wavelengths are also altered by the solar PV devices. According to TECNALIA measurements performed on ONYX panels, the area weighted visible transmittance is 0.269 for a 0.7 PVR. The lighting transmittance of the external windows is set to 0.808. It has been determined experimentally by TECNALIA. The lighting transmittance of the indoor windows is set to 0.8. For indoor surface reflection, the following lighting reflection coefficients are considered:

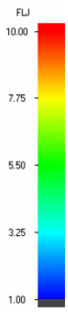
- Floor 0.2
- Walls 0.5
- Ceiling 0.8

The building rooms are modelled using DesignBuilder and simulated using the software Radiance [11]. An overcast sky is considered, it means that neither the orientation nor the time of the day have an influence on the obtained results. Only diffuse radiation is considered. The grid mesh size is variable and is ranging from 0.05m to 0.2m. To compute a lighting level, an external zenith illuminance of 10 000 lux is set.

To observe the effect of the BIPV on the occupant lighting comfort, we observe the influence of the configuration on:

- the variation of the Daylight Factor (DF) computed over an analysis grid located at 0.7m from the floor (typical height of a work plan). This indicator is the ratio of the light level at one point of the analysis grid to the light level outside the building.
- The % of surface of a room that reaches 300lux on the work plan using only natural lighting. The edge value of 300lux is selected according to the French labour code, it corresponds to the minimum accepting lighting level on a desk in an office space.





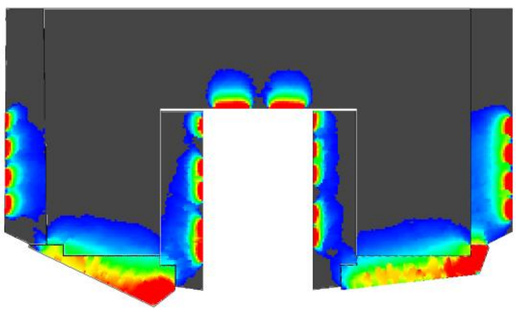


Figure 3.53 DEMO#6 – TECNALIA, Baseline configuration DF %

Figure 3.54 DEMO#6 – TECNALIA, Configuration with 72 ONYX modules DF %

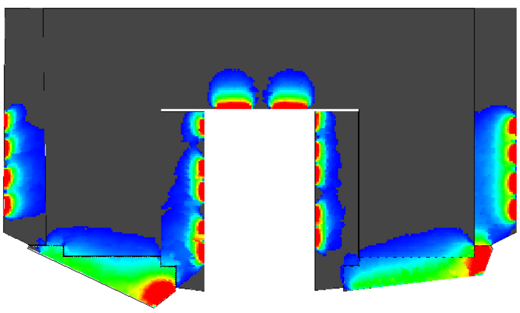


Figure 3.55 DEMO#6 – TECNALIA, Configuration with 96 ONYX modules DF %

Obviously, the office zones that will be affected by the installation of semi-transparent ONYX BIPV are the ones that share lot of windowed partition with the buffer zone behind the curtain zone. The table below gathers the results for the two previously described indicators for the baseline situation (without BIPV) and the configuration with the BIPV solution installed:

Table 3.9 DEMO#6 – TECNALIA, Illuminance > 300 lux for 3 scenarios

% surface > 300lux					
Zone	Baseline	72 modules		96 modules	
		72 Modules	Difference	96 modules	Difference
ExtOuest	16	13	3	13	3
OpenSpace	11	3	7	2	9
IntOuest	31	23	8	23	9
IntEst	21	15	6	15	6
ExtEst	30	26	4	26	4
Total	15	8	7	7	7

Table 3.10 DEMO#6 – TECNALIA, Average daylight factors for 3 scenarios

Mean daylight factor (%)					
Zone	Baseline	72 modules		96 modules	
		72 Modules	Difference	96 modules	Difference
ExtOuest	1.7	1.6	0.1	1.6	0.1
OpenSpace	1.0	0.6	0.4	0.5	0.5
IntOuest	3.0	2.8	0.2	2.8	0.2
IntEst	2.3	2.0	0.3	1.9	0.4
ExtEst	2.7	2.6	0.0	2.6	0.0
Total	1.4	1.1	0.3	1.0	0.4

According to these results, even in the baseline configuration and given the size of the office, natural lighting in the building is only available for the zones located close to the windows. In the base case, 15% of the surface of the modelled office space have an illuminance greater than 300 lux when external zenith illuminance is 10 000 lux. The mean daylight factor varies between 2.8% and 0.5%.

When adding a 72 modules transparent BIPV system, the surface where illuminance is greater than 300 lux decreases by 7%, and the mean daylight factor is depreciated by 0% to 0.4% depending on the office space considered.

If the number of modules is further increase to reach 96 modules, the available daylight will not decrease a lot. A large part of available daylight coming from the south buffer zones is already shut by the 72 modules. Most of the remaining daylight comes from the other windows.

These results indicate that the addition of the ONYX BIPV modules in front of the curtain wall will have a strong impact on the available daylight. However, given that in this building artificial lighting system is programmed to work on specific schedules, the impact on lighting consumption cannot be measured.

3.7.2.2 Impact on cooling needs

Simulation is carried out over a full year. For cooling needs, the results are analysed for the summer period 01/05 to the 30/09. The main heat gains and heat losses are aggregated for the whole building and are displayed on the following figure (cooling needs are represented as negative values):

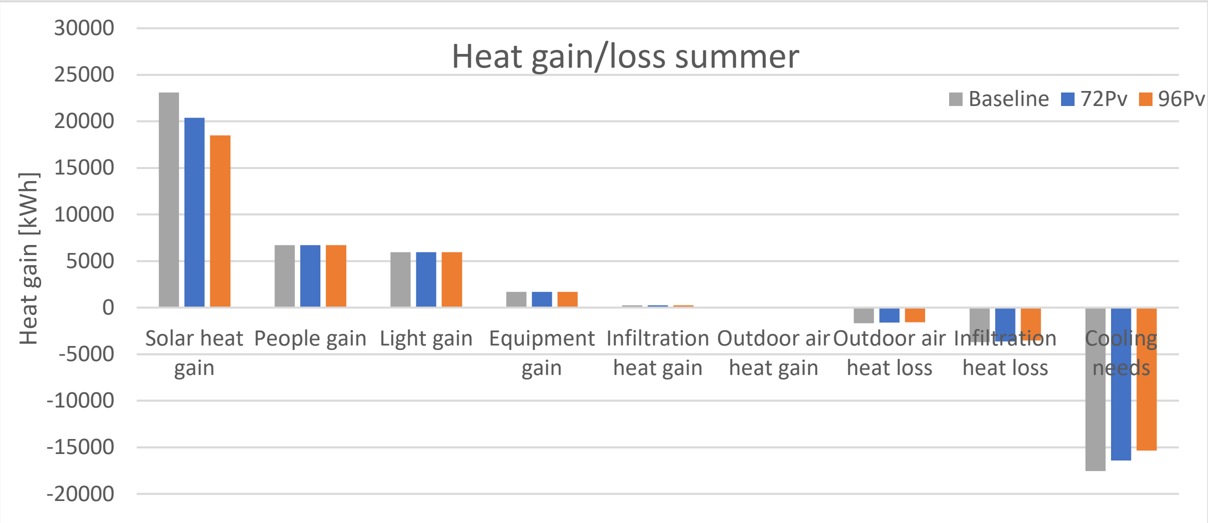
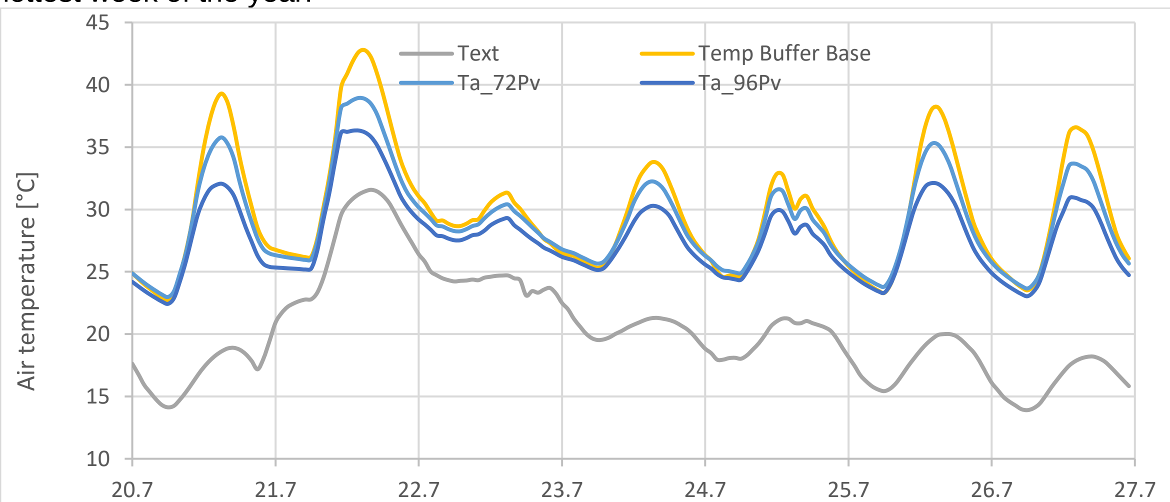


Figure 3.56 DEMO#6 – TECNALIA, - Heat gain/loss for summer period

The PV installation absorbs and reflects a part of the direct and diffuse solar radiation. The amount of solar heat gain is reduced in the two buffer rooms located behind the curtain wall. For the simulated part of the building, the amount of heat gain is reduced by 20% for the 96 modules system and by 12% for the de 72 modules installation.

According to these results, the PV installation is therefore supposed to affect the overall building cooling needs. A decrease of 13% of chiller needs can be observed on the simulated part for the fully PV covered solution. For the 72 modules variant, the cooling needs decrease by 7%. At the whole building level, the impact will be lower.

The figure below displays the temperature and the solar heat gain in one of the buffer zone during the hottest week of the year:



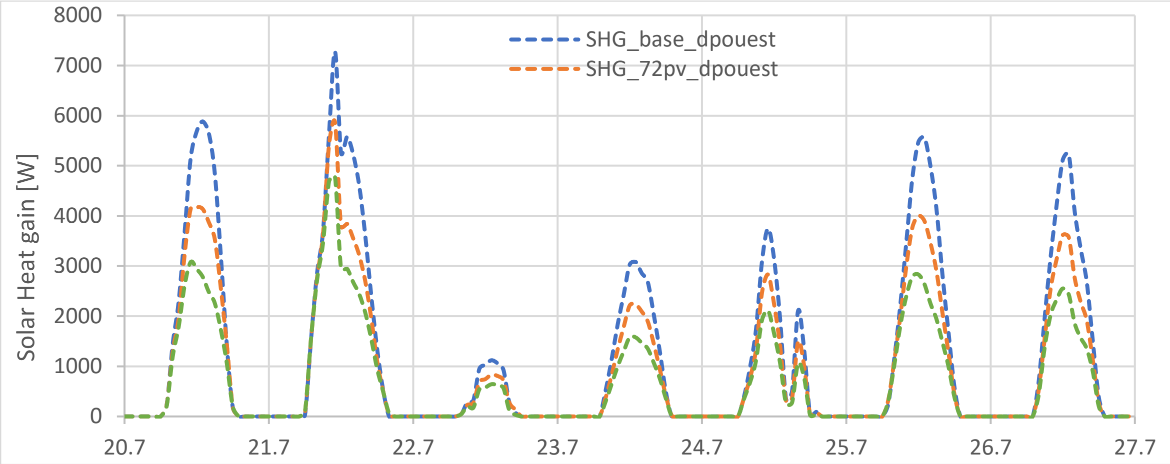


Figure 3.57 DEMO#6 – TECNALIA, Temperatures and solar radiation evolution during the hottest week

The difference in absorbed solar radiation induces a mean decrease of 0.8°C to 2°C in the buffer zone depending on the number of Pv modules. The maximum temperature difference is 7°C for the 92 modules and 4°C for the 72 modules. The two buffer zones are not cooled, and there is no airflow between them and the office space. Therefore, it is the reduced heat transfer through the partitions causes the cooling need decrease.

3.7.2.3 Impact on heat needs

Simulation is carried out over a full year. For heat needs, the results are analysed for the heating period ranging from the 01/01 to the 01/05, and from the 01/10 to the 31/12. The main heat gains and heat losses are aggregated for the whole building and are displayed on the following figure:

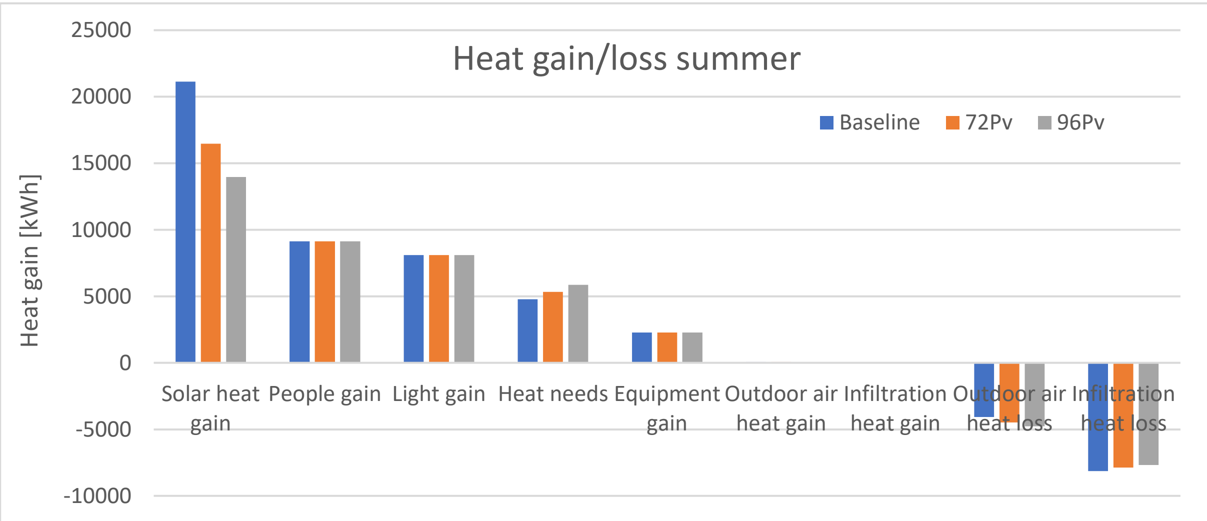


Figure 3.58 DEMO#6 – TECNALIA, - Internal heat gains

As for the summer period, the installation of ONYX BIPV modules reduces the solar heat gains by 34% for the 92 modules solution, and by 22% for the 72 modules system. The heat needs for the modelled part of the building are increased by 12% to 23% depending on the number of solar BIPV.

The following graph displays the heat needs and the air dry bulb temperature in the open space zone, for the simulation of the baseline configuration and the configuration with BIPV modules.

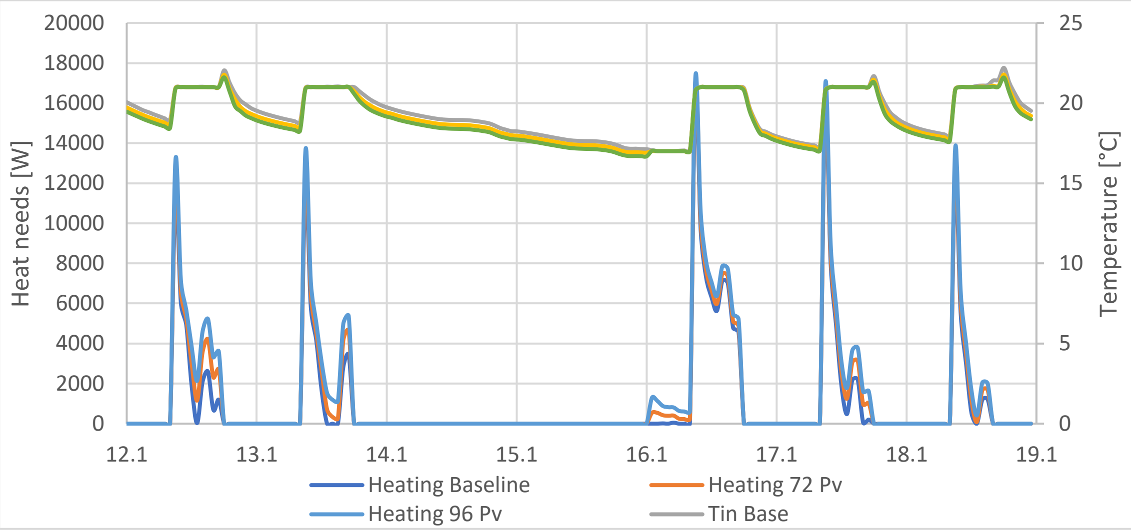


Figure 3.59 DEMO#6 – TECNALIA, Open space heat needs and temperature

In this graph, the temperature of the office space without the BIPV is slightly higher than the one evaluated for the 2 variants with ONYX modules. This is due to the fraction of solar radiation absorbed or reflected by the PV modules that doesn't heat the buffer zones, and that is not transmitted to the open space. The result is a slightly increased demand of heat power needed to reach the temperature set point. However, this increase of 3% required heat power will not affect the building behaviour.

3.7.2.4 Conclusion for TECNALIA demo site

ONYX transparent product has a non-negligible impact on the building thermal behaviour and on lighting availability. The addition of PV cells in front of the windows reduces both visible and mid-range solar radiation.

Regarding lighting energy consumption, the building uses a clock regulation. The impact of BIPV product cannot be measured, but lighting level on desks located close to the curtain wall is supposed to diminish.

Regarding thermal needs, the cooling needs will be reduced while the heat needs will be increased. For the part of the building that has been modelled, the overall balance indicates a reduction of 5% in thermal needs (heating + cooling) for the 96 modules system and of 3% for the 72 modules installation. These results must be taken with caution as they are based on strong hypotheses (geometry, internal gain, indoor temperature, etc.). Also, they only concerns the restricted modelled part of the building.

4 DEMO-SYSTEMS SIMULATION BY PVSITES BIPV MODELLING TOOL

4.1 Simulation methodology by PVSITES BIPV modelling tool

4.1.1 Overall methodology

The overall methodology consists on:

a. CADCAMation develops the PVSITES software, first for integrated simulation performance at building level with BIPV and BAPV systems, second for PVSITES products virtualization.

b. Inputs

   The PVSITES software is designed to import 3D geometry through various formats:

   - SketchUp native (.SKP)
   - Generic ISO BIM (.IFC)
   - Green Building (gbXML)
   - EnergyPlus (.IDF)

   Weather data come from METEONORM® (.tm2) or EnergyPlus weather files (.epw). Each demo site is geo-localized within the first user interface and the data imported in the same time from internal database.

c. BIPV Modeling-Simulation

   The PVSITES software runs contextual simulation in real time to bridge the gap between 3D modeling and performance calculation:

   - Primary modeling comes from the original model (architect, designer): CAD 3D file;
   - Step#1 – Environment: 3D model generation, weather data, albedo selection, sun course, shadowing, sun exposure;
   - Step#2 – Irradiance: global yearly to hourly direct and diffuse irradiance simulation (kWh/m2) using our own raytracing technologies. Shadowing effects on energy ratio;
   - Step#3 - BIPV layouts: configuration of PVSITES products (cell editor to glazing editor) using FLISOM and ONYX Solar datasheets (from WP3/WP4). Virtual objects handling from user (mouse+click) enables integration of modules, tiles, on selected surfaces; global performance is computed and displayed: installed power (kWp), modules area (m2), array yield (kWh/kWp), yearly production (kWh), shadow losses, heat losses. The software enables shadowing calculation at element level (module);
   - Step#4 - Inverter selection and wiring: the user is able to configure his own inverter or select inverter(s) from the PHOTON database. At the current stage of the project we are not able to integrate PVSITES inverters due to lack of final parameters from developers of these systems. Additionally, this step is avoided due to the downstream processing where DC production is required. Cable / wiring specifications enable users to interact with the balance of system. Cable losses can be computed.

- Step#5 – Results: DC production is displayed at PV layout level and from inverters at various time steps (yearly to hourly). Shadow losses, heat losses, cable losses and mismatching losses are computed and displayed as well. We have extracted outputs (production, hourly) in CSV files to feed the downstream processing (TECNALIA with inverter optimization).

The locations and the configurations of the BIPV systems used to simulate the buildings are the one described in the D8.3 V01 digest.

4.1.2 Modelling strategy retained for transparent BIPV

The software has been developed to fit with ONYX Solar strategies regarding glazing systems and transparent BIPV products. The module configurator is based on 4 editors:

- Cell editor
- Pattern editor
- Transparent Glass editor
- Glazing editor

To design a transparent BIPV system, the user has to use the following steps:

BIPV Layout

Balance of System

Figure 4.1 Steps to design a transparent BIPV system

4.1.3 Modelling strategy retained for Opaque BIPV

The software has been developed to fit with ONYX Solar strategies regarding opaque glass / glass systems and hidden busbars cells. The module configurator is based on 4 editors:

- Cell editor
- Pattern editor
- Opaque Glass editor
- Glazing editor

To design an opaque BIPV system, the user has to use the following steps:

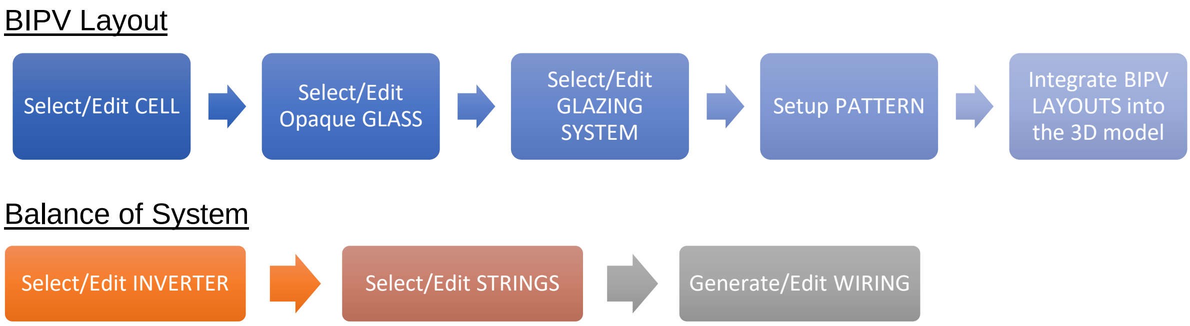


Figure 4.2 Steps to design an opaque BIPV system

4.1.4 Modelling strategy retained for CIGS films mounted as cladding system

The software has been developed to fit with FLISOM strategies regarding CIGS PV technologies mounted on metal substrate (steel, aluminium) to generate cladding modules and roof tiles. The module configurator is based on 2 editors working as a BAPV configurator:

- Cell editor
- Module editor

To design a CIGS cladding BIPV system, the user has to use the following steps:

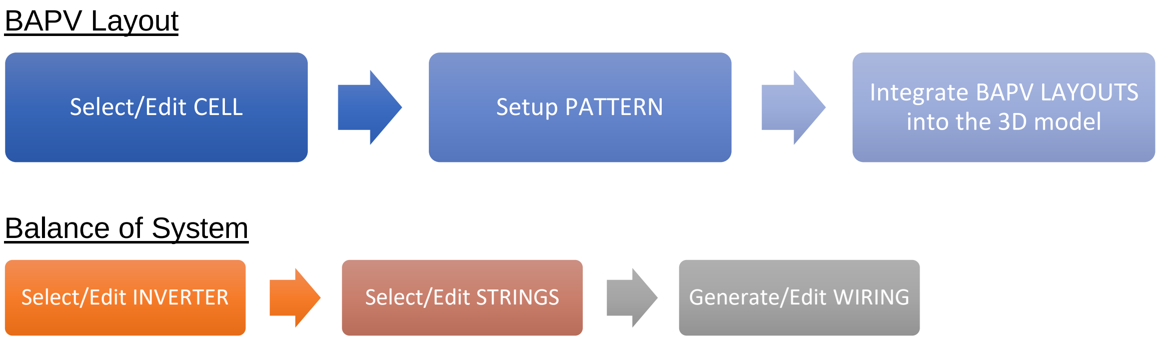


Figure 4.3 Steps to design a CIGS cladding BIPV system

4.2 DEMO#1 – Format D2 house, simulation by PVSITES BIPV modelling tool

4.2.1 Hypothesis

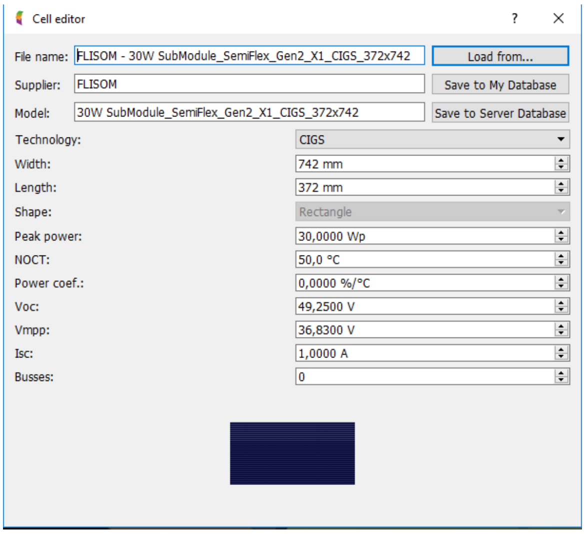


Figure 4.4 Configuration of 30Wp FLISOM standard submodule as a cell for PVSITES calculation.

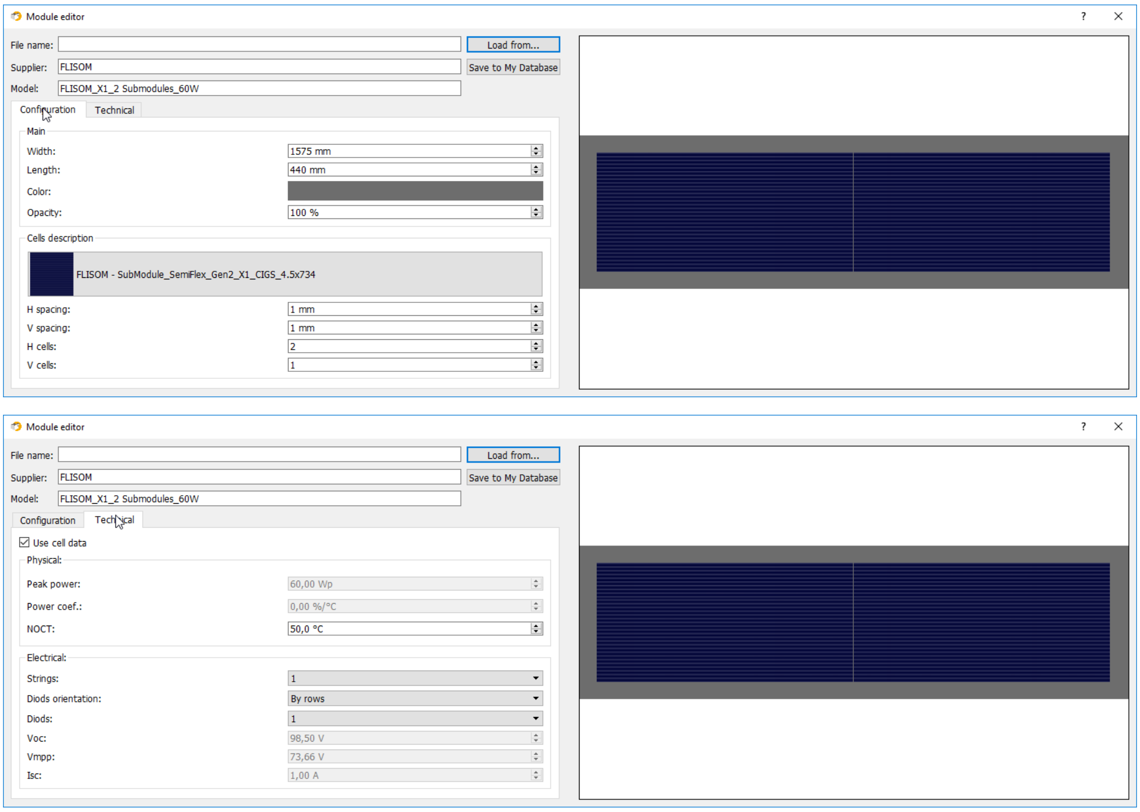


Figure 4.5 The 1x60Wp X1 module for FD2 roof is made of 1 row of 2 submodules.

Figure 4.6 Modelling has been made as much realistic as it could be from the architect (TrimbleTM SketchUpTM model)

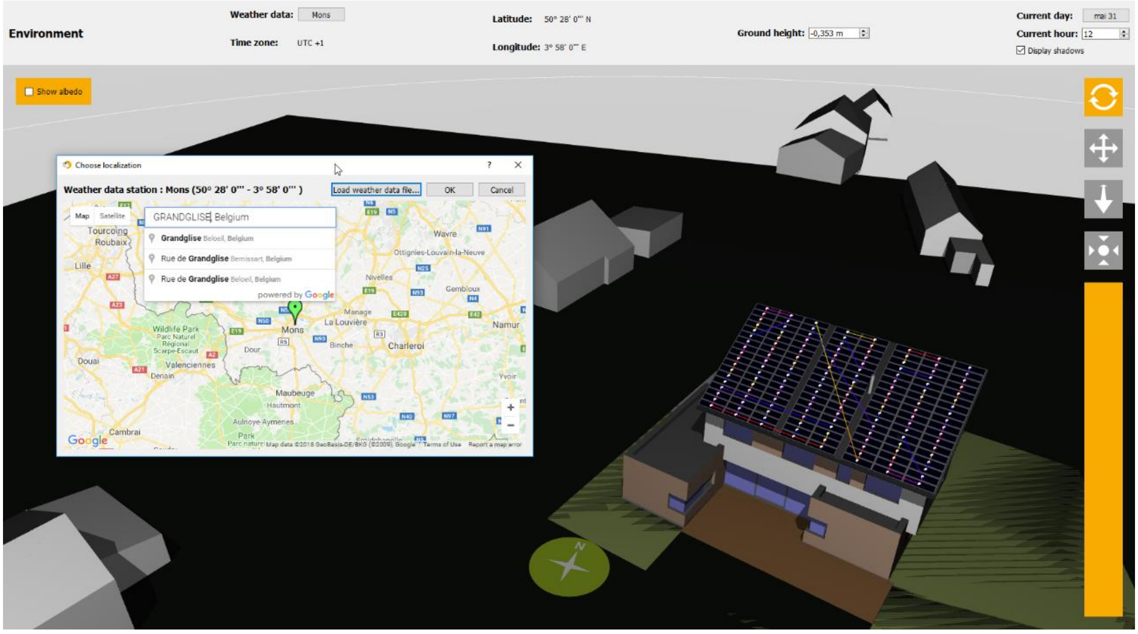


Figure 4.7 Geo location - Importation of closest weather data from data base or from file

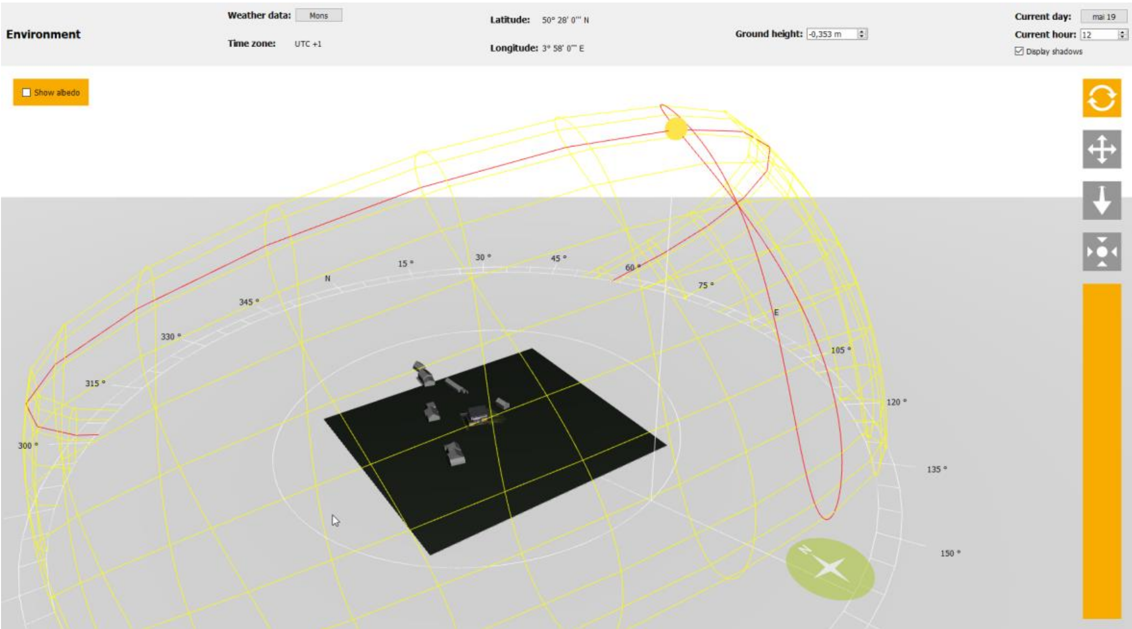


Figure 4.8 Close and far shadowing calculation are made possible through 3D modelling of realistic buildings - Sun course for full year is displayed at hourly step time

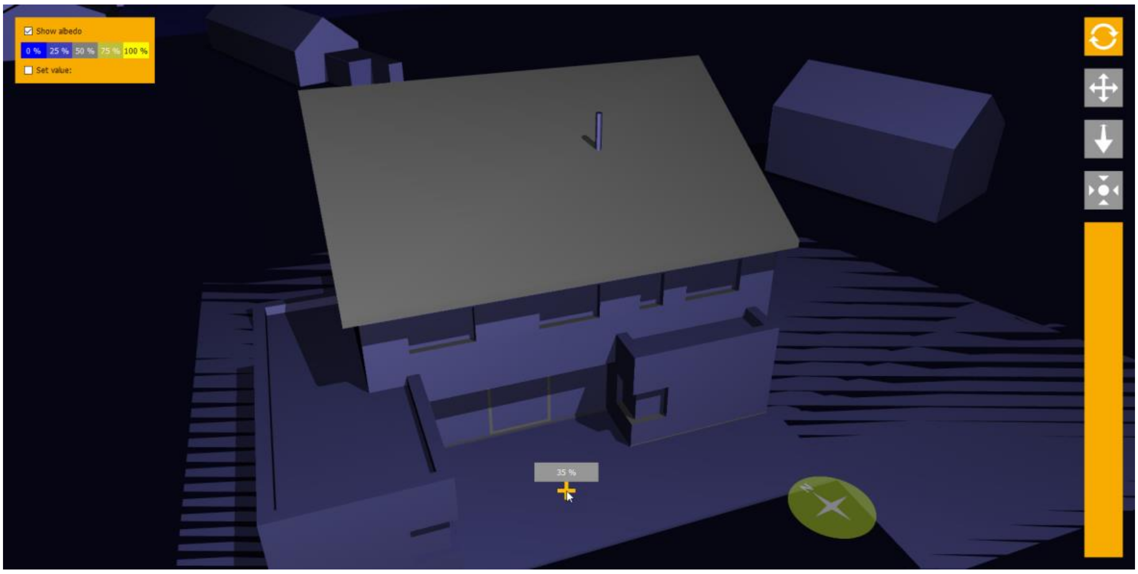
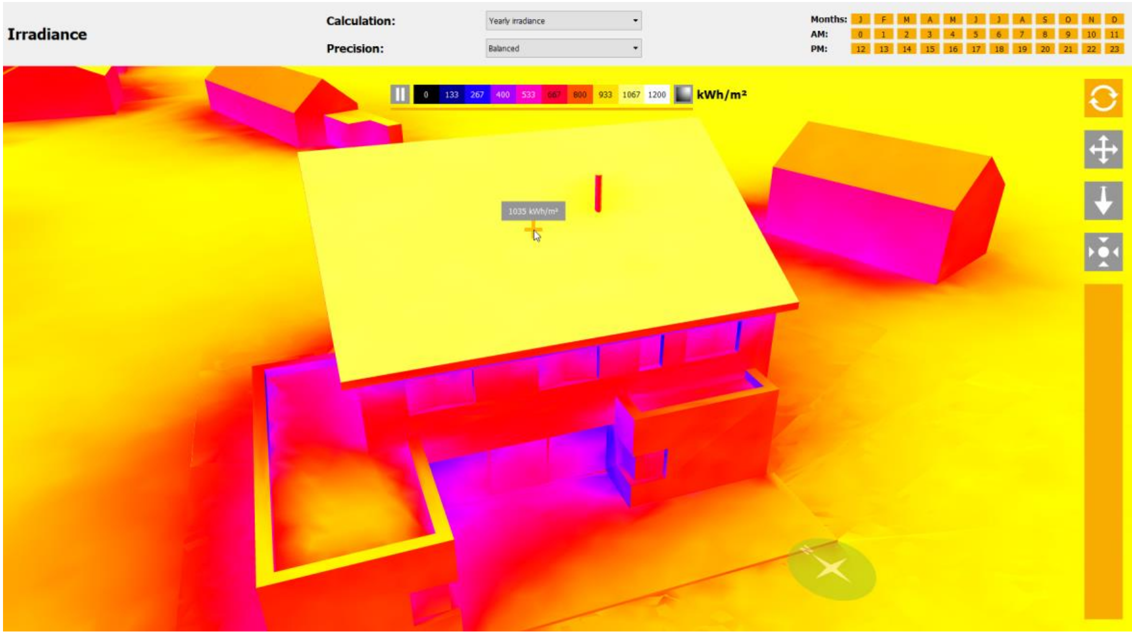


Figure 4.9 Albedo effects (reflected irradiance) are generated selecting groups and types of surfaces

4.2.2 Results



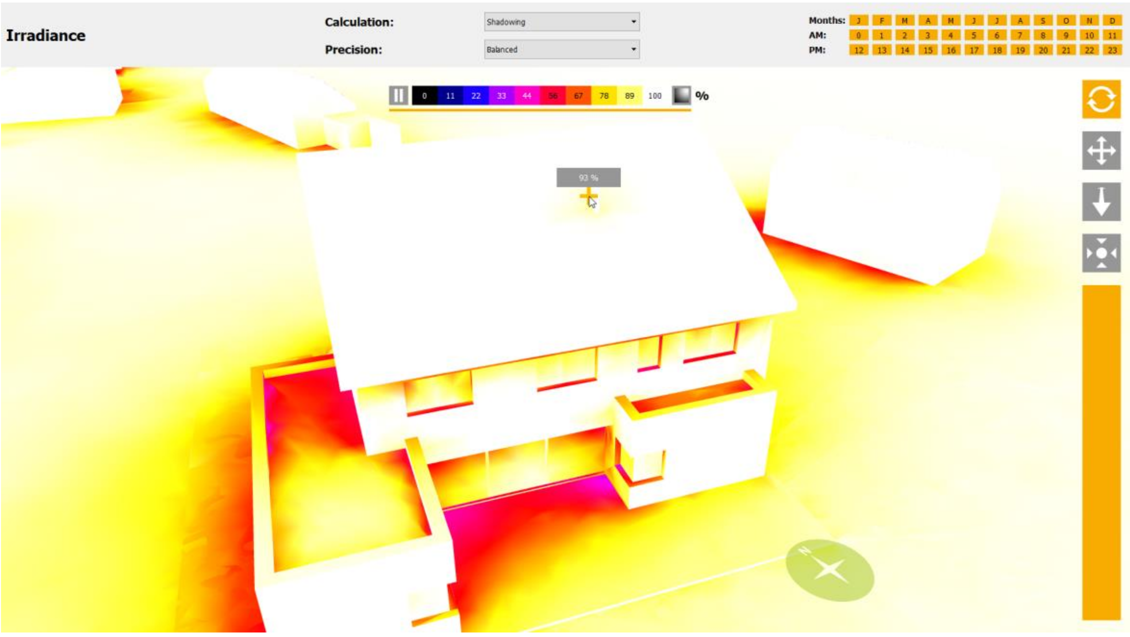


Figure 4.10 Irradiance computation: yearly irradiance expected=1035kWh/m2 on the middle of the roof. No shadowing losses on the roof (100% reception of available irradiance) except the one due to the small chimney

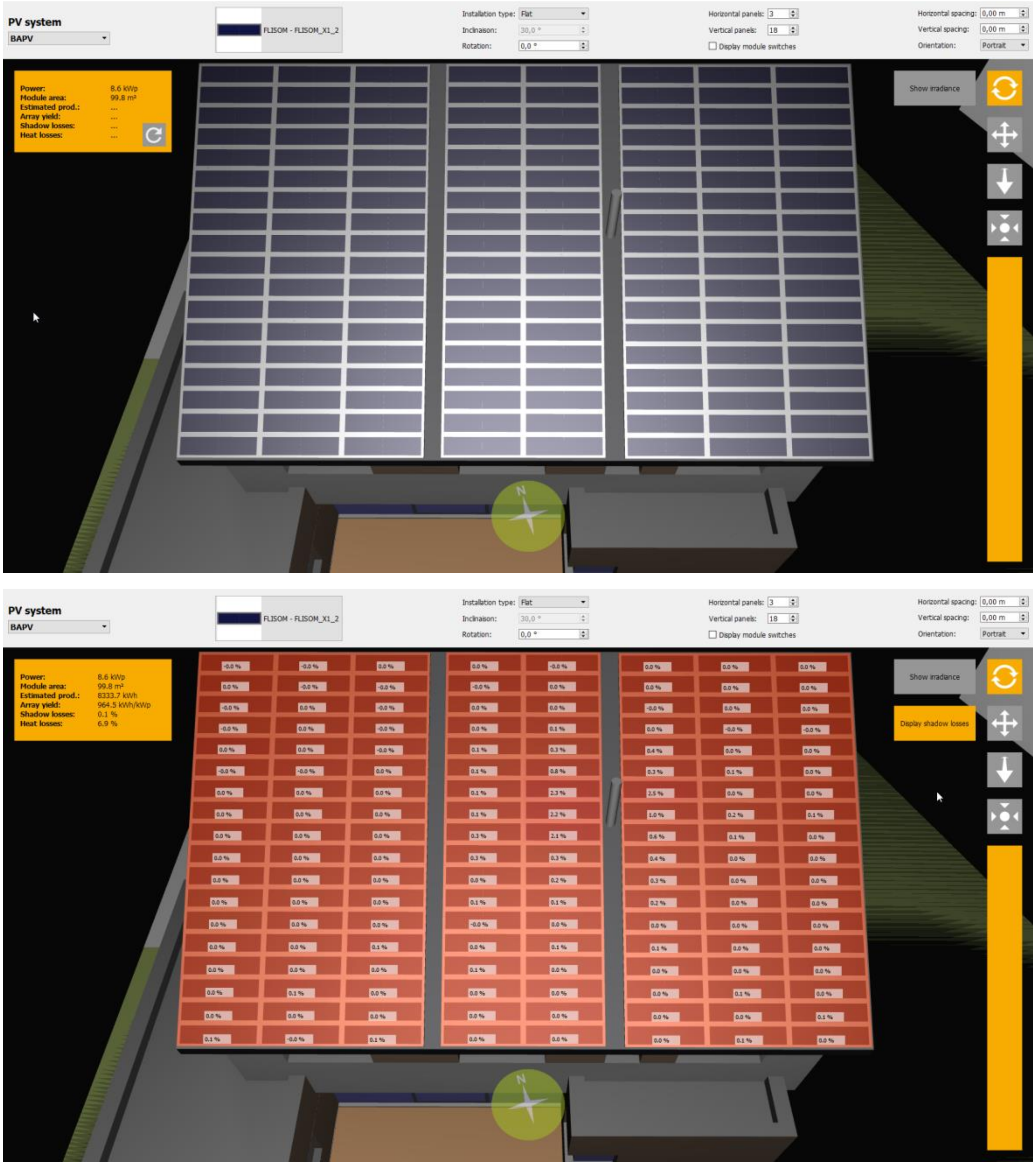


Figure 4.11 CIGS layout: 144 modules; 8.6kWp; 98.8sqm; annual production 8,333kWh; array yield 965kWh/kWp; positive albedo, no shadow losses (except close to chimney)

Every single module is computed as a system and the software displays KPIs.

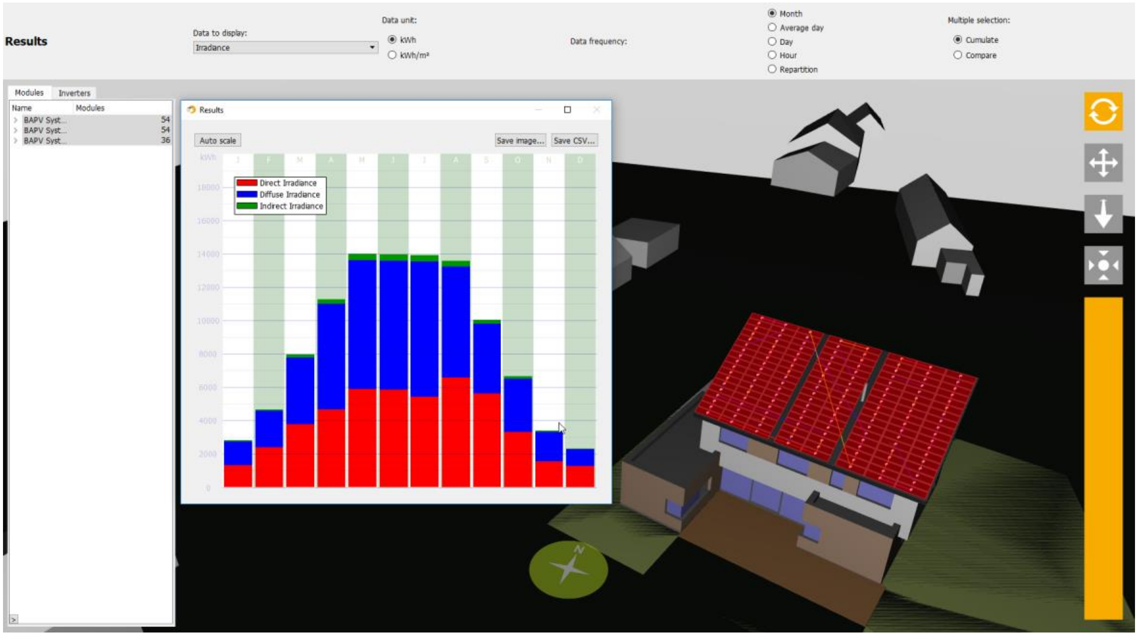


Figure 4.12 Irradiance computation: Diffuse Irradiance exceeds direct irradiance

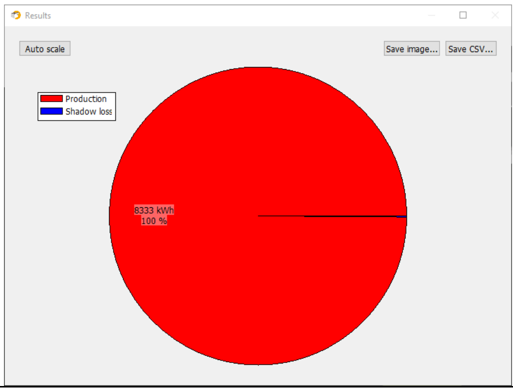


Figure 4.13 Global Production before BoS = 8,333 kWh

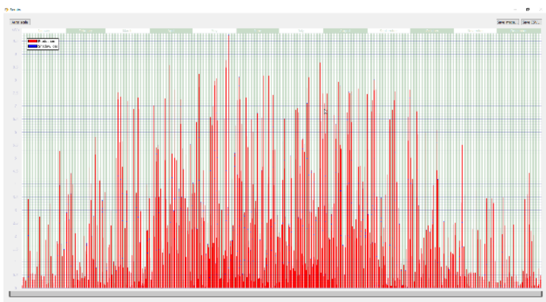


Figure 4.14 Hourly production; csv exportation to downstream processing (PVSITES planning tool)

4.2.3 Conclusions

At the current stage of the validated performance of the software and provided the fact that products and project are submitted to updates we consider that the first results are positive and we did not face critical difficulties in the process. Next step will be comparison between measurement and simulation as soon as the modules will be integrated. Thermal impact will be also implemented.

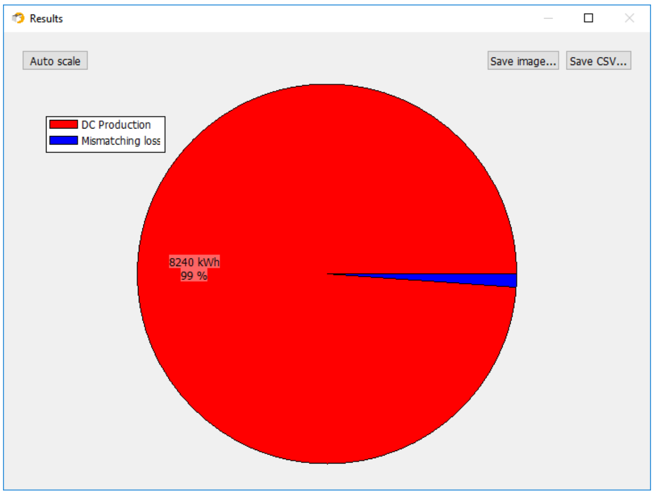


Figure 4.15 Global DC Production from typical inverter - Mismatching loss

4.3 DEMO#2 – EHG, simulation by PVSITES BIPV modelling tool

4.3.1 Hypothesis

Figure 4.16 Modelling has been made as much realistic as it could be from the architect (SketchUp model)

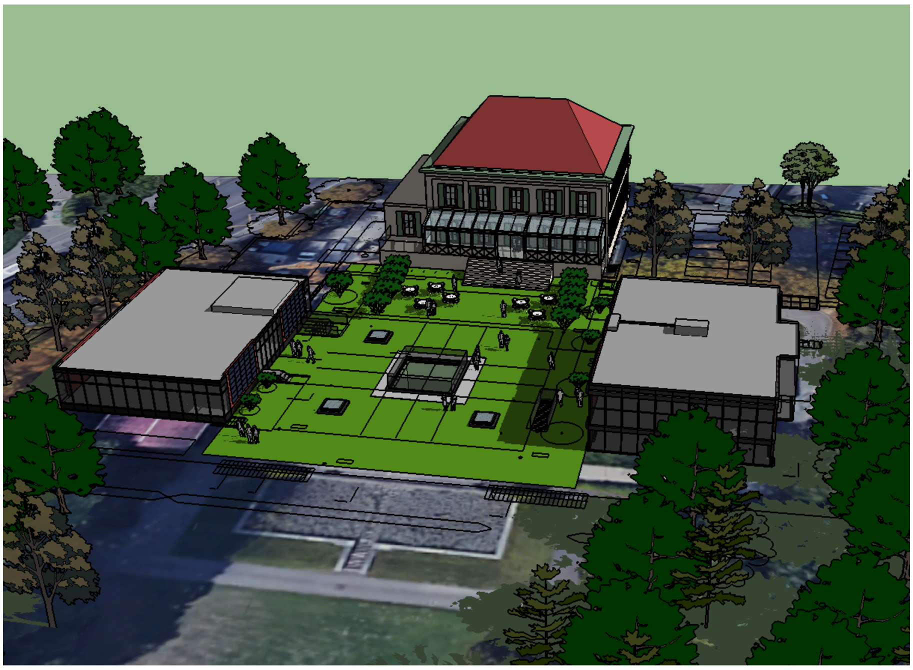


Figure 4.17 3D model © BEAR-iD Architecture

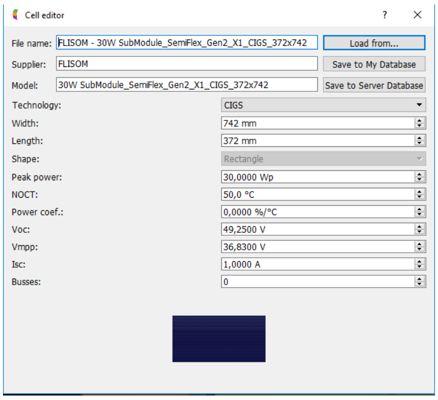


Figure 4.18 Configuration of 30Wp FLISOM standard submodule as a cell for PVSITES simulation.

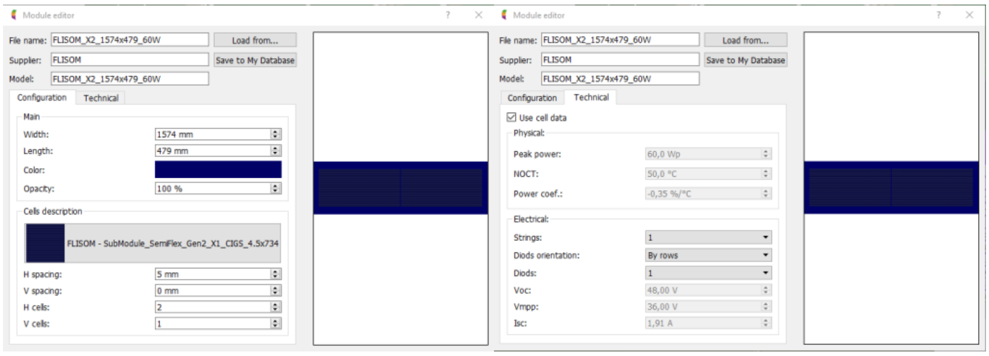


Figure 4.19 From 30Wp modules to 120Wp modules for EHG facades are made of 1 to 4 submodules

4.3.2 Results

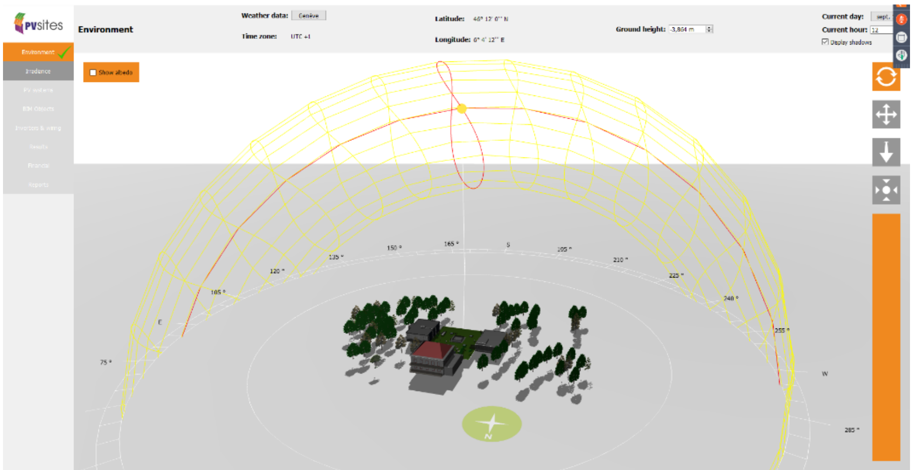


Figure 4.20 Nearby masks (trees) illustrated through simulation integrating sun course. METEONORM® TM2 weather data

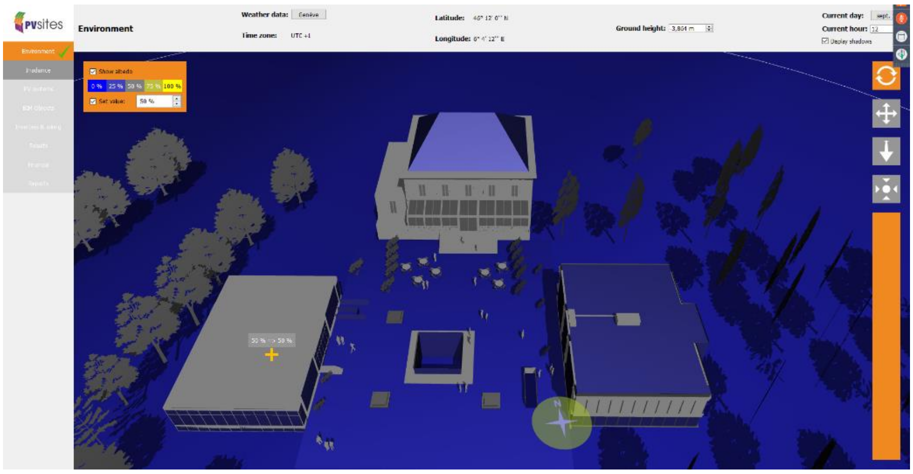


Figure 4.21 We paid attention to albedo selection for ground and building surfaces (energy gains): 50% for brightest parts

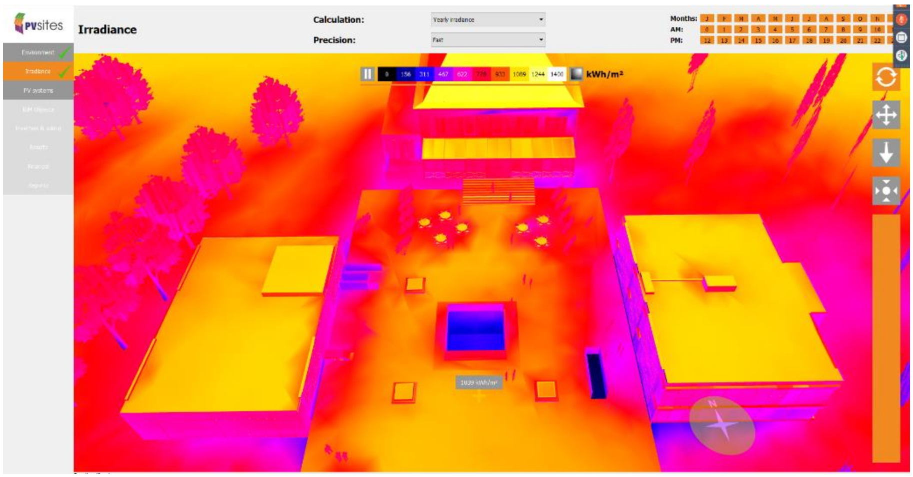


Figure 4.22 Yearly irradiance: shadowing effects on pavilions facades due to orientation (East/West and trees)

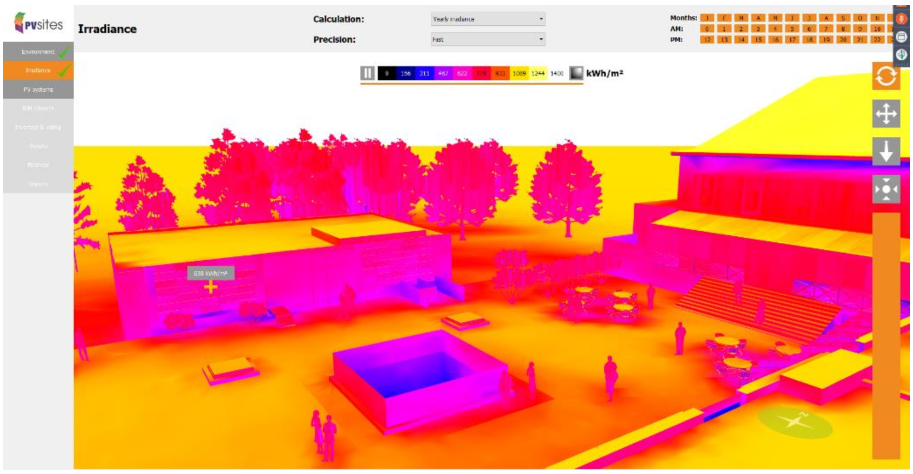


Figure 4.23 Yearly irradiance: shadowing effects on Pavilion 1 (West facade). Trees to be removed to prevent PV extinction in the future

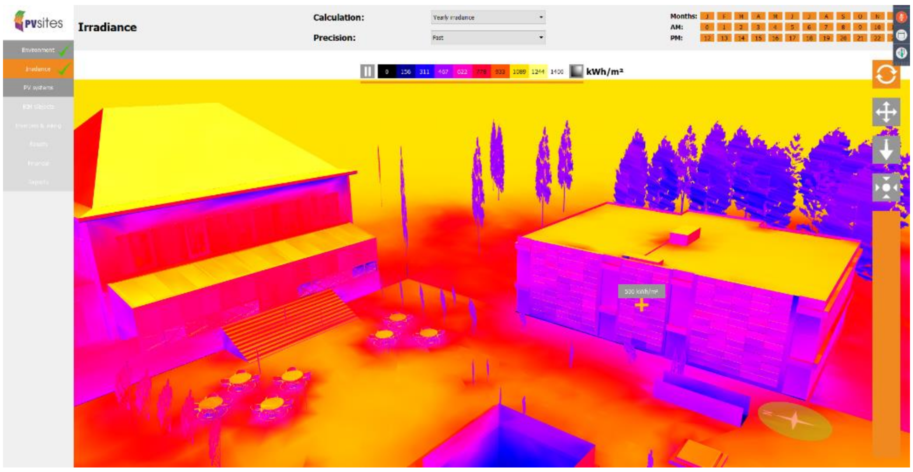


Figure 4.24 Yearly irradiance: shadowing effects on Pavilion 2 (East facade). Trees to be removed to prevent PV shutdown in the future (trees are supposed to grow then generate more shadowing losses)

Figure 4.25 PV layouts on Pavilion #1: 2 distinctive layouts of 1x2 FLISOM X2 60Wp modules – BAPV mounting

Figure 4.26 Production on Pavilion 1 (West facade). KPIs: Power=2.5kWp (30sqm); Array yield=705kWh/kWp; Total production=1,776kWh/y; albedo effects are huge and enable production (22.8%)

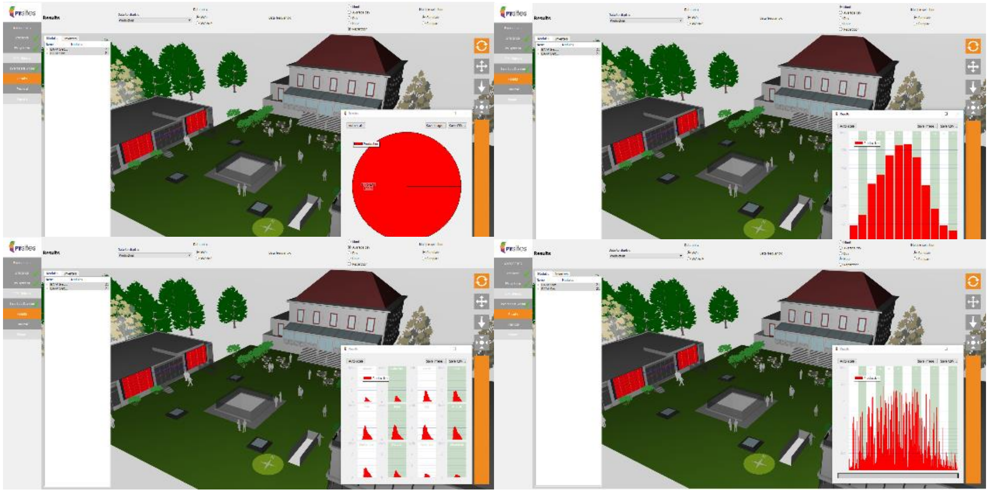


Figure 4.27 Production on Pavilion 1 (West facade); 1,776 kWh distributed from yearly to hourly time step; csv exportation to downstream processing (PVSITES planning tool).

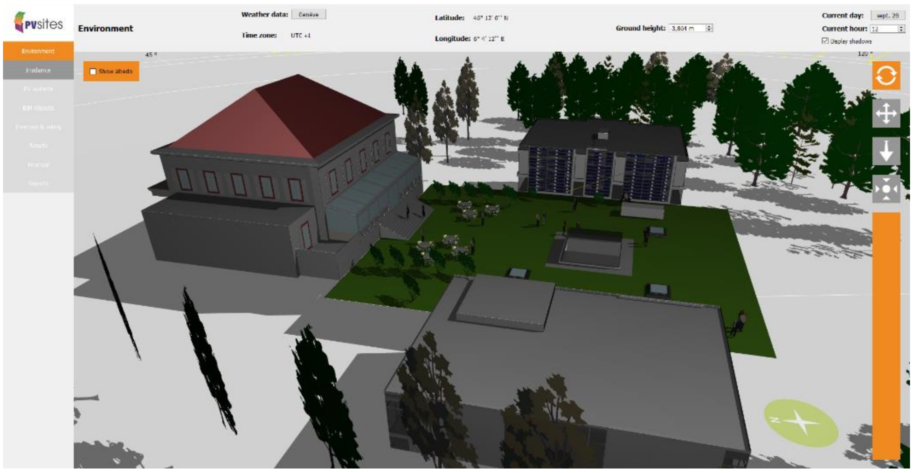


Figure 4.28 PV layouts on Pavilion #2: 3 distinctive layouts of FLISOM X2 modules (30Wp to 120Wp) – BAPV mounting

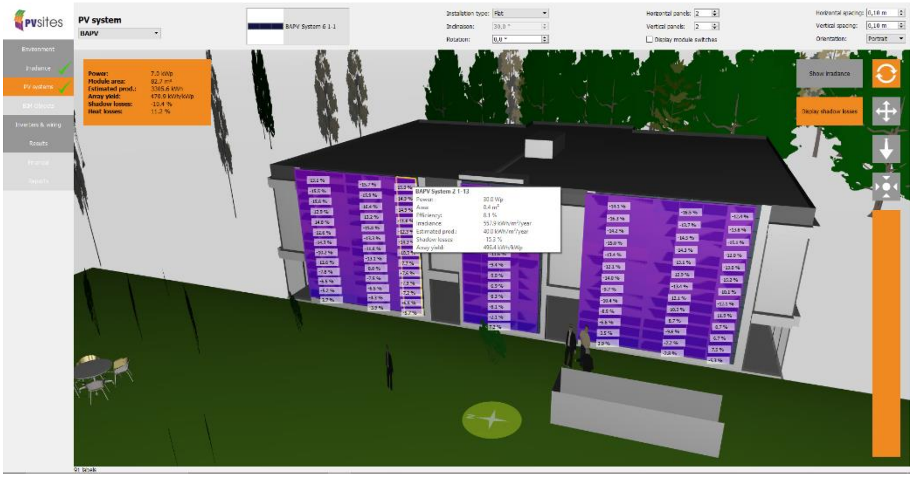


Figure 4.29 Production on Pavilion 2 (East facade). KPIs: Power=7kWp (83sqm); Array yield=471kWh/kWp; Total production=3,306kWh/y; albedo effects are significant and enable production (10.4%)

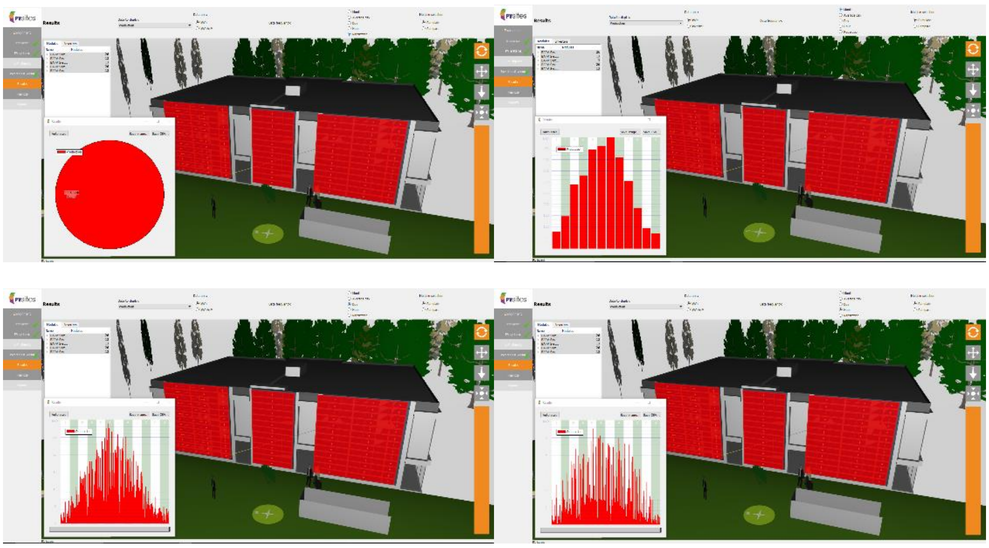


Figure 4.30 Production on Pavilion 2 (East facade); 3,306kWh distributed from yearly to hourly time step; csv exportation to downstream processing (PVSITES planning tool)

4.3.3 Conclusions

EHG pavilions facades were not supposed to be the better location for PV production. Our simulations confirm these assumptions as they take into account far and close masking for the sun course then for direct irradiance.

Diffuse irradiance generated from albedo effect has been considered and is very significant for electrical production.

At the current stage of the performance of the software and provided the fact that products and project are submitted to updates we consider that the first results are realistic and we did not face critical difficulties in the process. Next step will be comparison between measurement and simulation as soon as the modules will be integrated. Thermal impact will be also implemented.

4.4 DEMO#3 – CARPORTS of EMPA and EKZ facilities, simulation by PVSITES BIPV modelling tool

4.4.1 Hypothesis

We have faced issues creating curved virtual modules compatible with the 3D model and even oversized CIGS panels. To stick to the agenda, we chose to use equivalent elementary flat modules (based on the elementary 30Wp FLISOM submodule) that are not exactly the final configuration (under development).

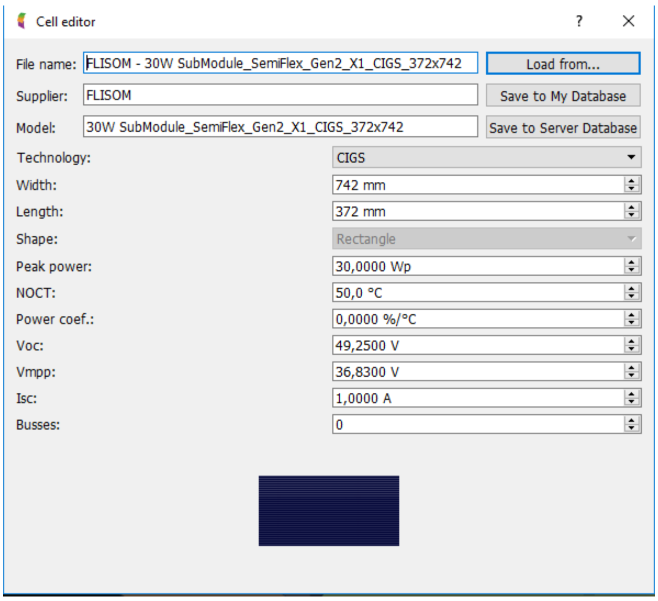


Figure 4.31 Configuration of 30Wp FLISOM standard submodule as a cell for PVSITES simulation

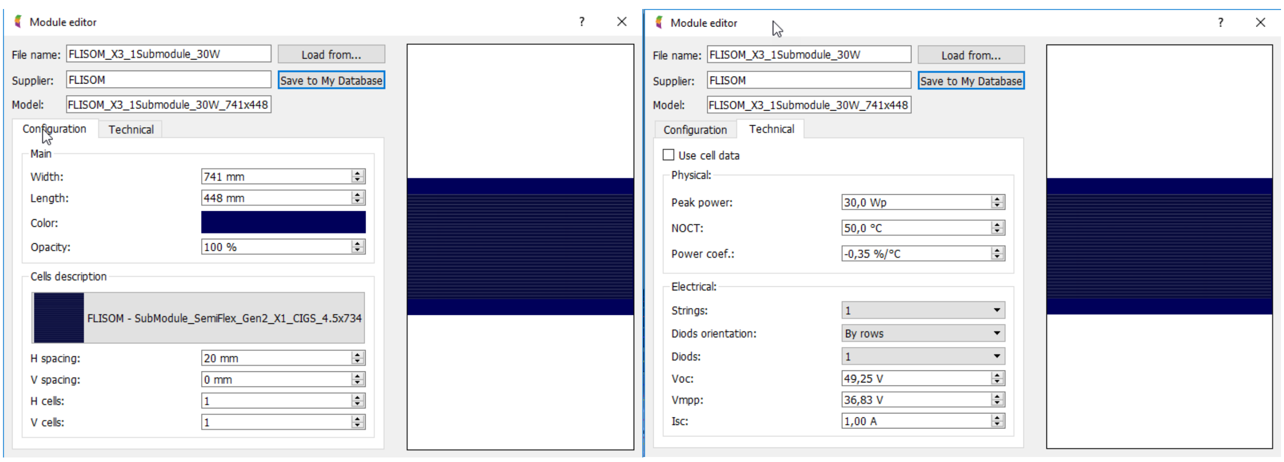


Figure 4.32 We have faced issues creating curved virtual modules compatible with the 3D model and even oversized CIGS panels. To stick to the agenda, we chose to use elementary modules (same size of the elementary 30Wp submodule)

Figure 4.33 EKZ Carport - 3D model © BEAR-iD Architecture

Figure 4.34 EMPA Carport - 3D model © BEAR-iD Architecture

Modelling has been made as much realistic as it could be from the architect as a 3D drawing under SketchUp software (drafted by BEAR-iD). The 3D file has been separated in 2 in order to lighten the 3D content: EKZ carport / EMPA carport. We had to slightly lighten the original model (too many weighting details for simulation; some trees were not needed for simulation).

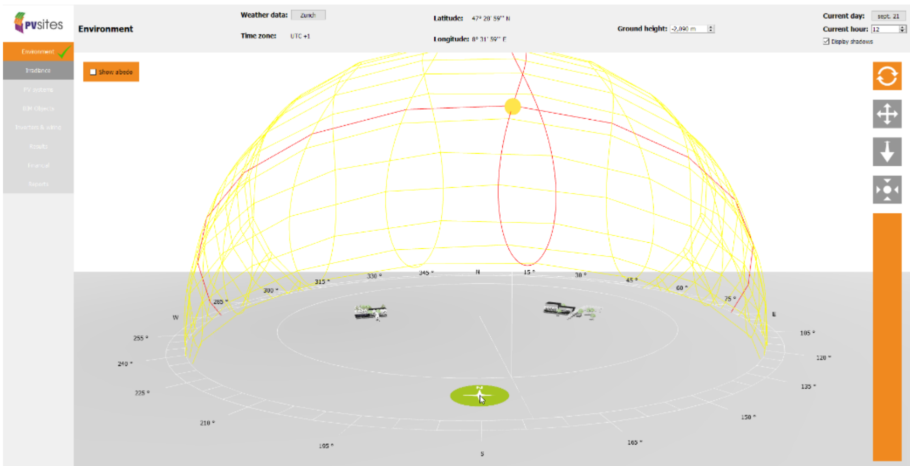


Figure 4.35 Close and far shadowing calculation are made possible through 3D modelling of realistic buildings. Left: EKZ Carport / right EMPA carport with correct orientations. Albedo effects (diffuse irradiance) are generated selecting groups and types of surfaces

4.4.2 Results

EKZ CARPORT:

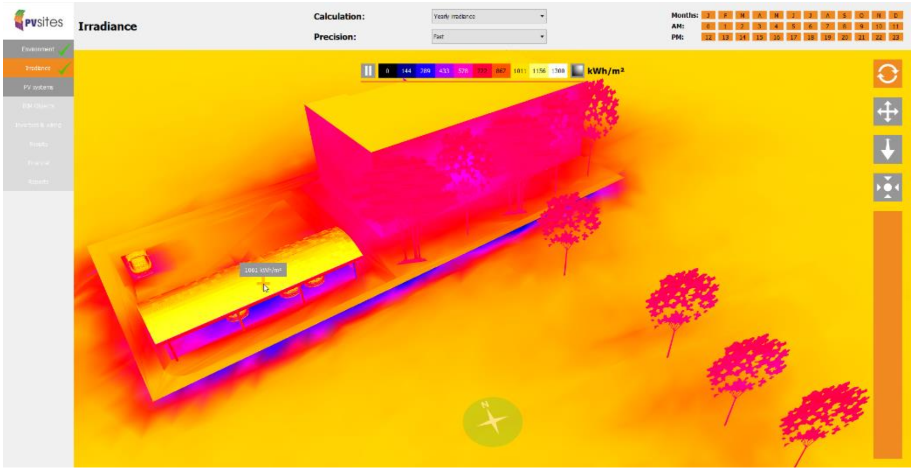


Figure 4.36 Results for EKZ carport: global direct + diffuse irradiance

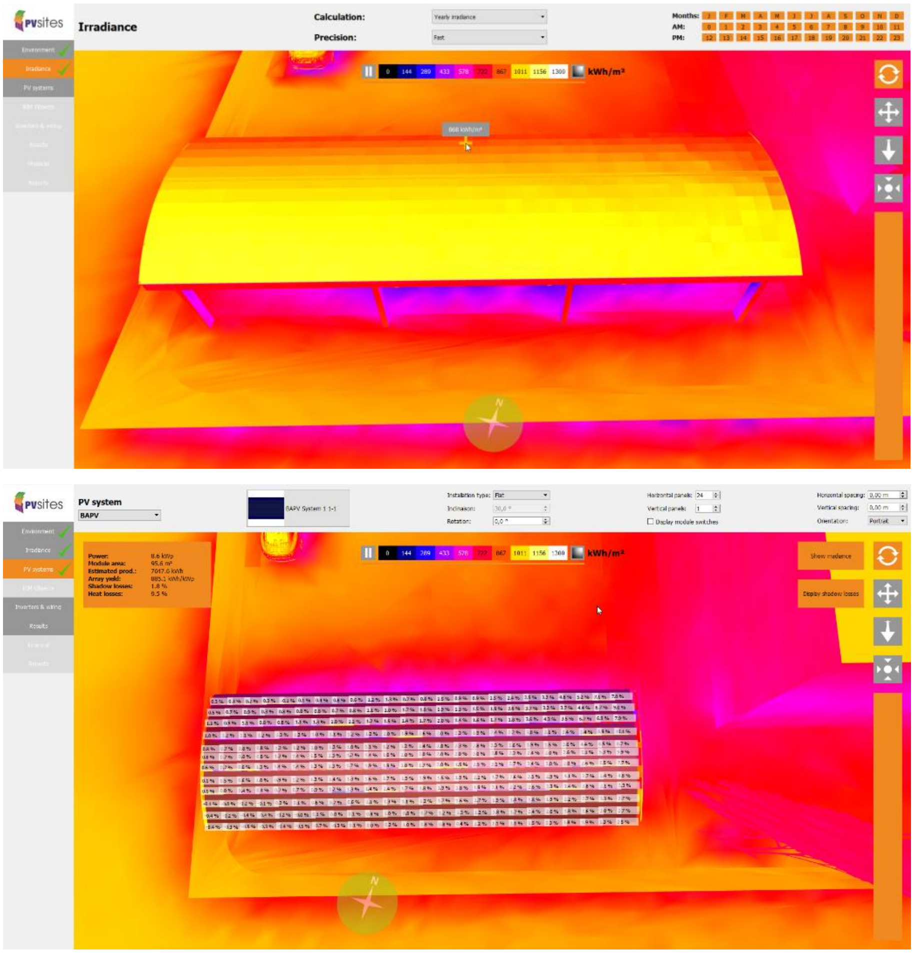


Figure 4.37 Irradiance computation with PV layout: yearly irradiance expected=1061kWh/m2 on the middle of the roof, South, 868 kWh/m2 North. Shadowing losses on the North (up to 10% due surrounding buildings)

BAPV layout: 2 rows of 24 submodules; 8.6kWp; 95.6sqm; array yield 885kWh/kWp; no albedo effect; low shadowing (1.8%). Every single module is computed as a system and the software displays KPIs.

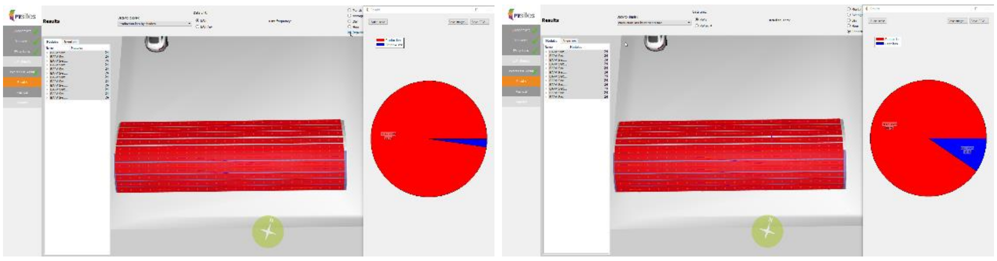


Figure 4.38 Global Production = 7,647 kWh / 2% shadow losses / 10% Heat losses

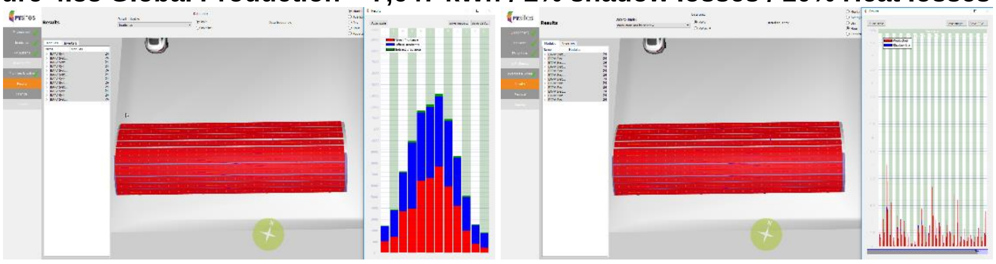
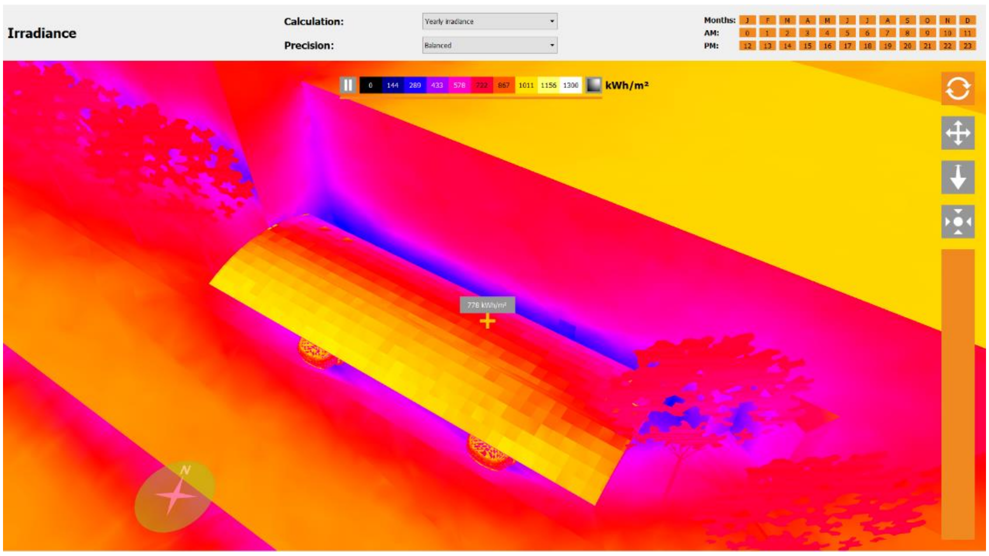


Figure 4.39 Left: Yearly Irradiance: direct / diffuse / indirect. Right: Hourly production; csv exportation to downstream processing (PVSITES planning tool)

<u>EMPA CARPORT:</u>



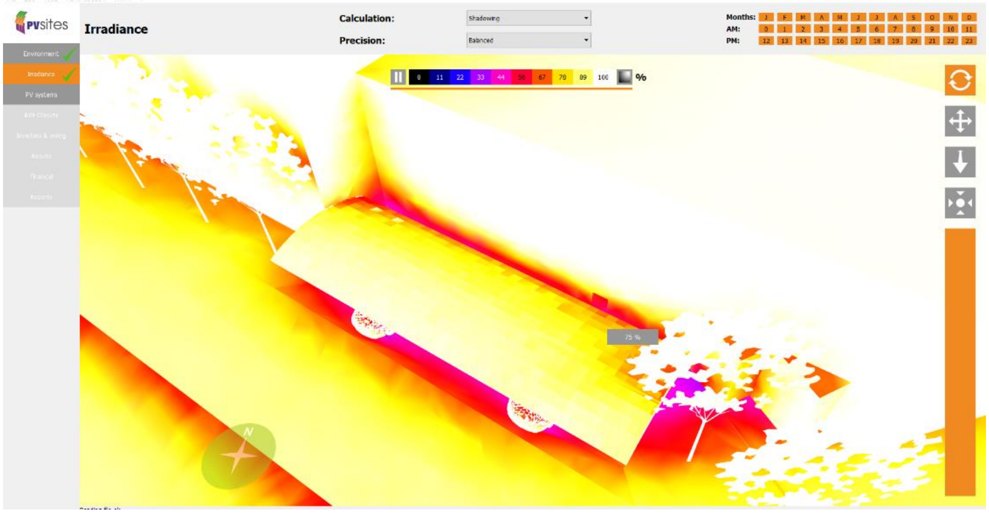


Figure 4.40 Results for EMPA carport: global direct + diffuse irradiance + shadowing effects due to trees + close building

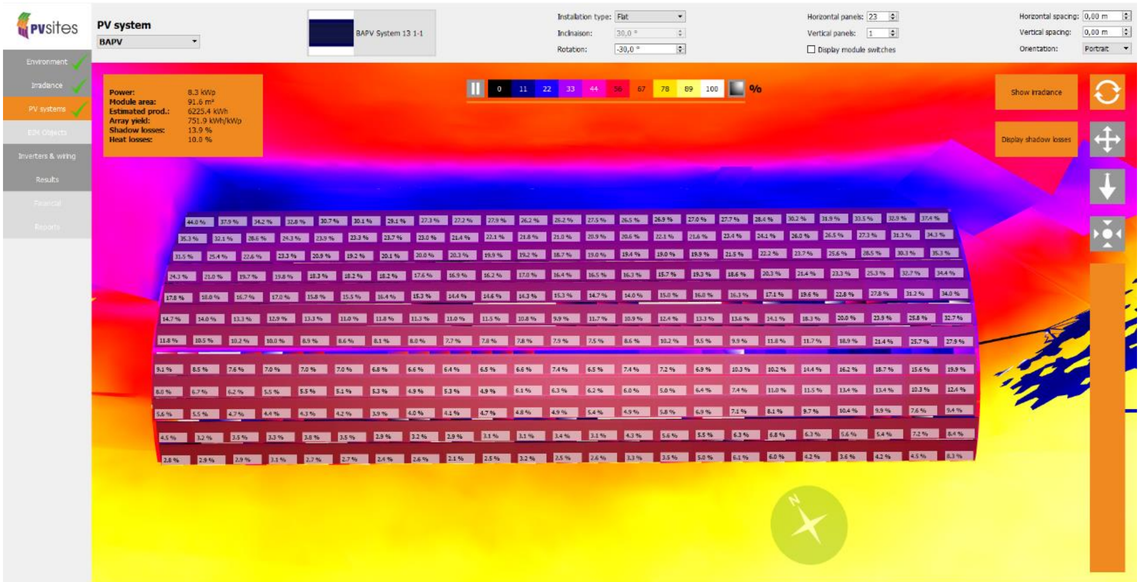


Figure 4.41 EMPA Carport - Irradiance computation with PV layout: yearly irradiance impacted: 778 kWh/m2 North. Shadowing losses on the North side (up to 44% due surrounding buildings and vegetation)

BAPV mode layout: rows of 23 submodules; 8.3kWp; 91.6sqm; array yield 751.9kWh/kWp; high albedo effect (North); very high shadowing due to surroundings. Every single module is computed as a system and the software displays KPIs

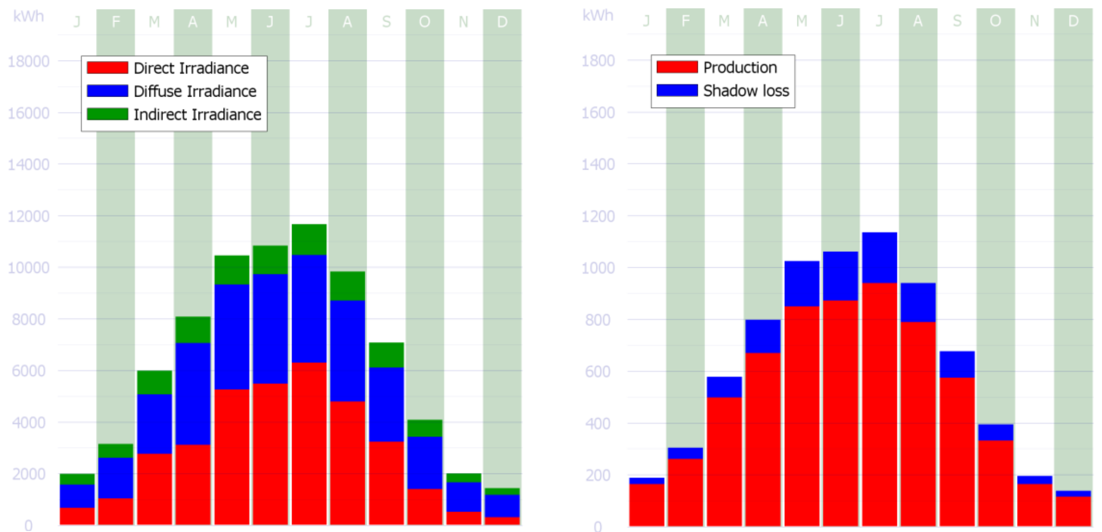


Figure 4.42 EMPA Carport - Left: Yearly Irradiance: direct / diffuse / indirect. Right: Monthly production + shadow losses

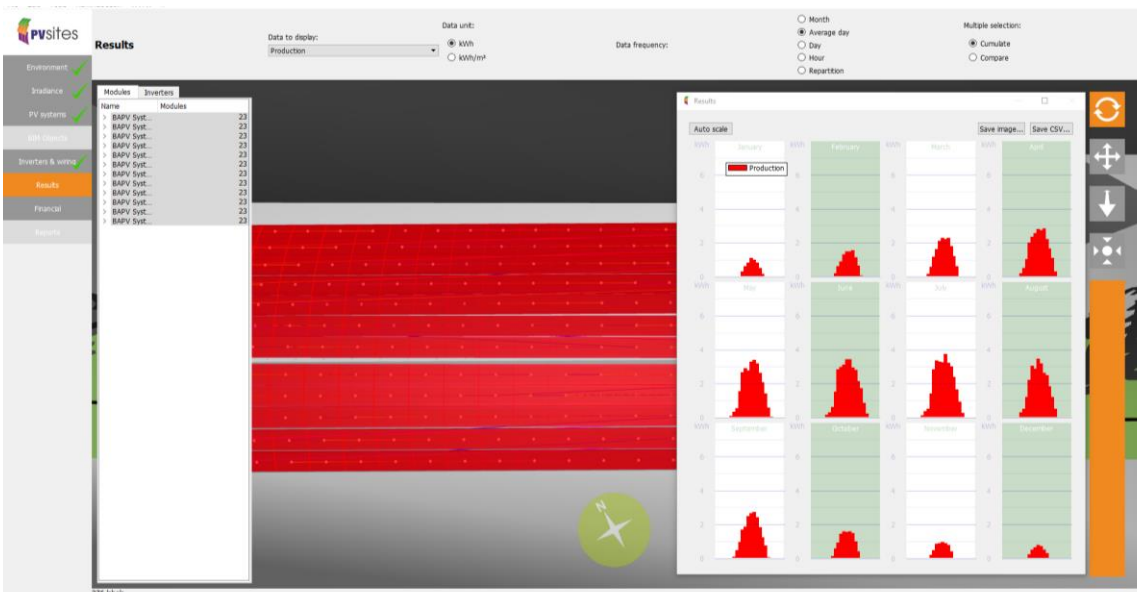


Figure 4.43 EMPA Carport - Up: average daily production; Down: Hourly production; csv exportation to downstream processing (PVSITES planning tool)

4.4.3 Conclusions

At the current stage of the performance of the software and provided the fact that products and project are submitted to updates we consider that the first results for irradiance and production are positive but we had to use elementary submodules to generate the PV equivalent surfaces, which can be considered as realistic for earliest simulations. Next step will consider the development of specific X3 products in line with FLISOM latest specifications and architectural issues.

4.5 DEMO#4 – CRICURSA building, simulation by PVSITES BIPV modelling tool

4.5.1 Hypothesis

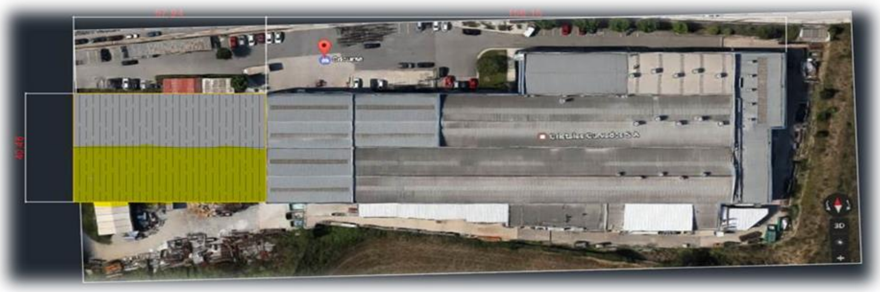


Figure 4.44 Modelling has been made as much realistic as it could be from the architect (SketchUp model)

We have noted that too many details (roof panels edges) may cause slowness for simulation with the PVSITES software.

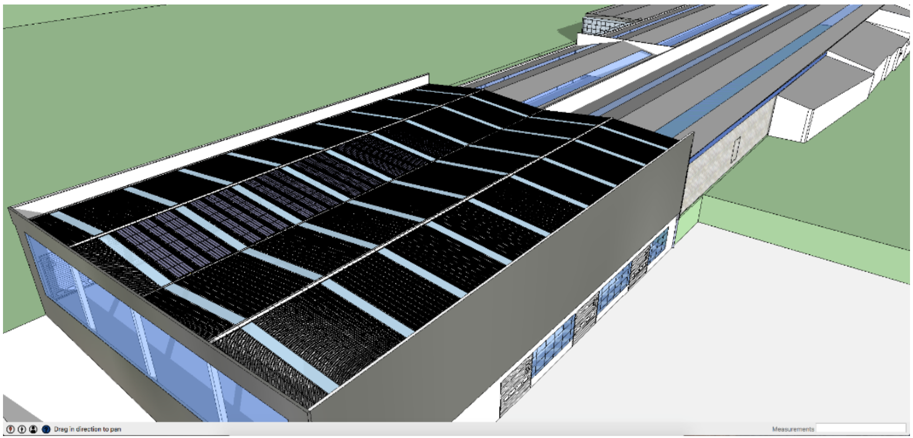


Figure 4.45 3D model © BEAR-iD Architecture

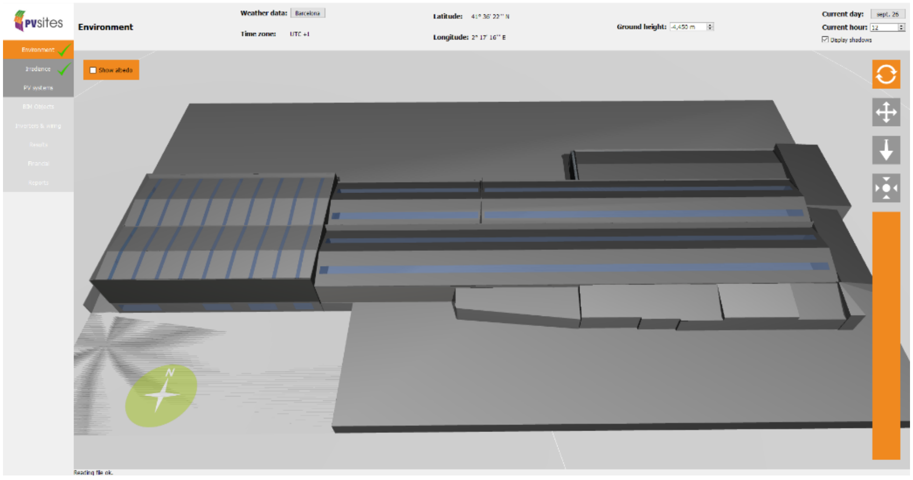


Figure 4.46 Importation of the 3D model into PVSITES. Geo-location METEONORM® TM2 weather data

Too many geometrical details cause slowness to camera/handling. Albedo settings: no need because of roofing configuration.

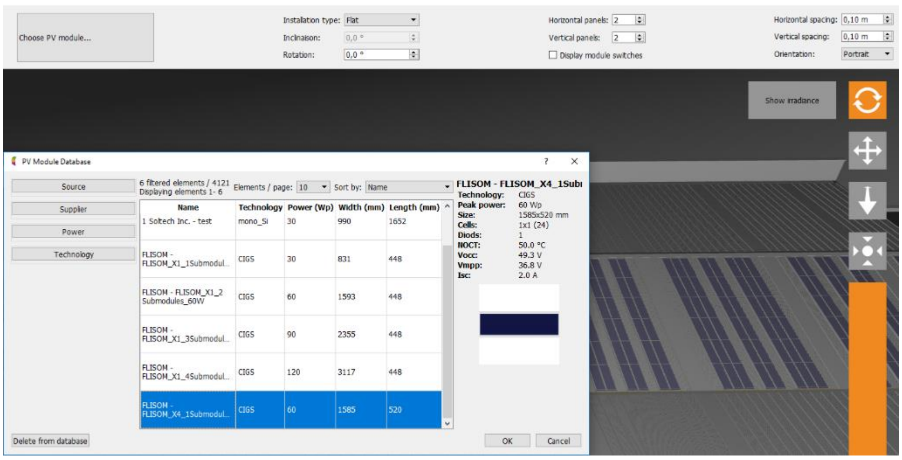


Figure 4.47 Rows of 1x60Wp X4 modules for CRICURSA roof (made with 2 submodules)

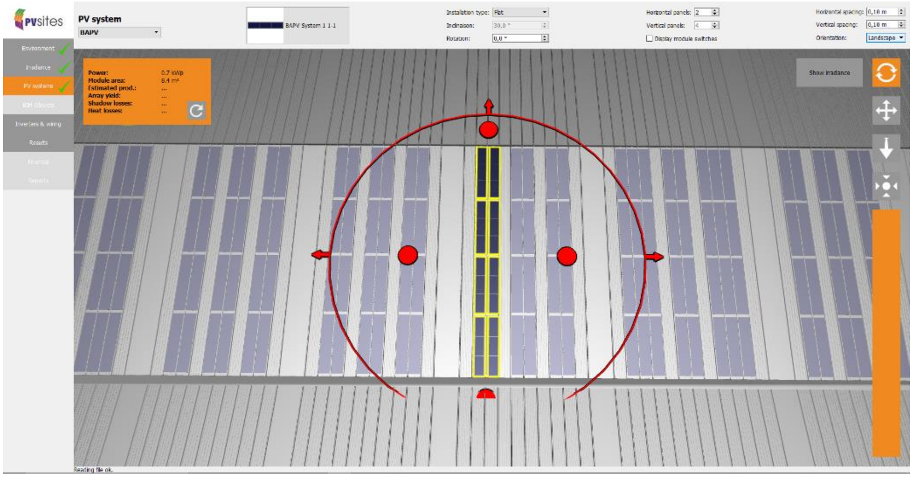


Figure 4.48 We chose to use the BAPV mode within the software as modules are not integrated in the building skin

4.5.2 Results

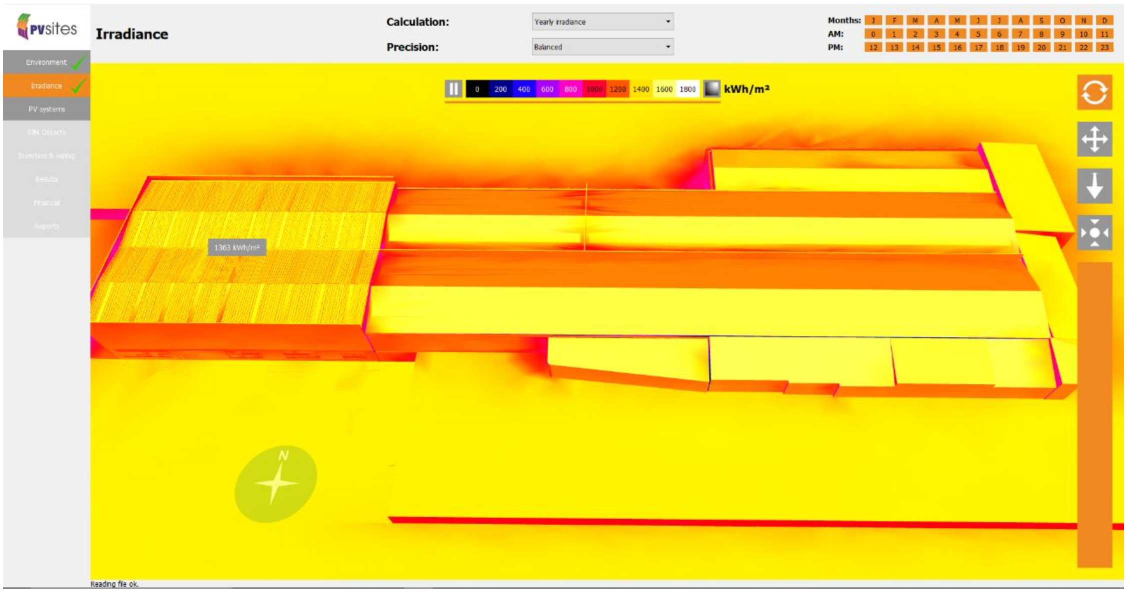


Figure 4.49 Yearly irradiance: shadowing losses = none. The roof gets plain direct irradiance

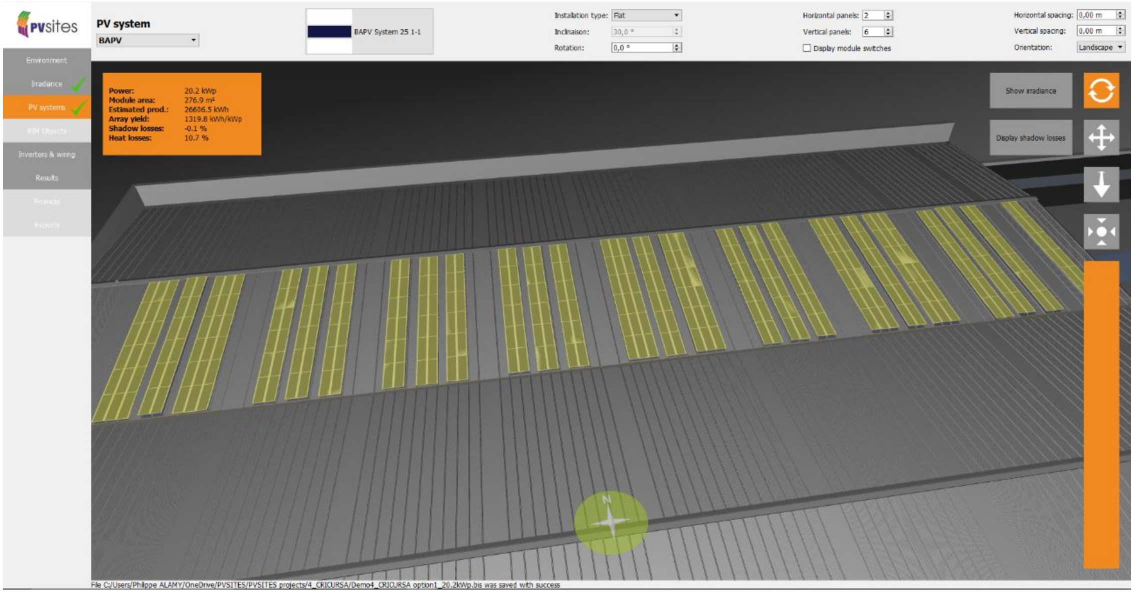


Figure 4.50 Production of the PVsystem. KPIs: Power=20kWp (277sqm); Array yield=1,320kWh/kWp. Total production=26,606kWh/y; albedo effects are non significant; no shadowing losses; significant heat losses (10.6%)

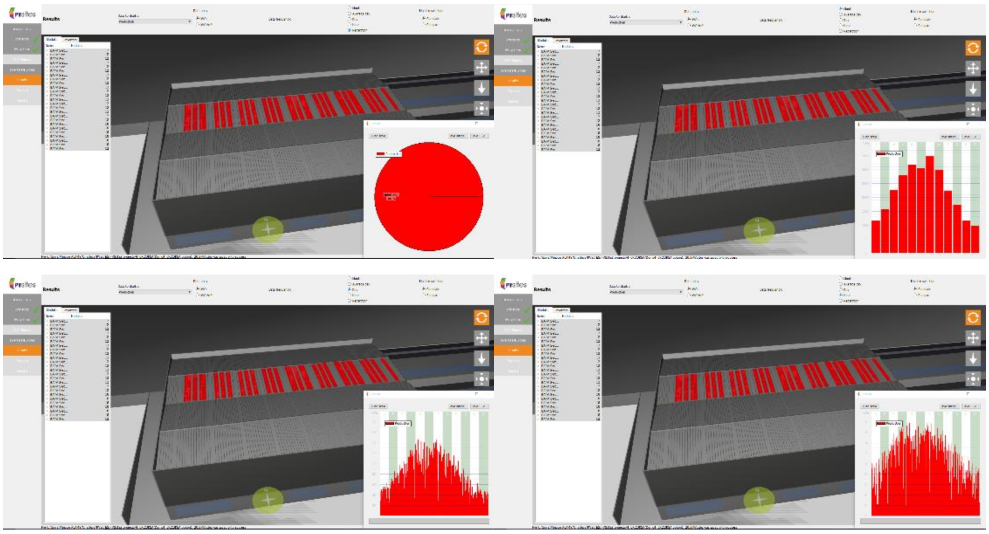


Figure 4.51. Production on CRICURSA's roof. 26,606kWh distributed from yearly to hourly time step; csv exportation to downstream processing (PVSITES planning tool)

4.5.3 Conclusions

CRICURSA's roof was supposed to be the better location for PV production in this area. Our simulations confirm these assumptions with an array yield of 1,320kWh/kWp.

Reflected irradiance generated from albedo effect has been neglected because non-significant in this kind of roofing configuration.

Heat losses are significant (10.6%). This prediction has to be challenged by measurement in real conditions and our thermal models could be improved for GIGS technologies.

At the current stage of the performance validation of the software and provided the fact that products and project are submitted to updates we consider that the first results are realistic and we did not face critical difficulties in the process. Next step will be comparison between measurement and simulation as soon as the modules will be integrated. Thermal impact will be also implemented.

4.6 DEMO#5 – Vilogia building, simulation by PVSITES BIPV modelling tool

4.6.1 Hypothesis

Figure 4.52 Modelling has been made as much realistic as it could be from the architect (SketchUp model). Trees are not virtualized which could be create a gap between simulation and reality.

Figure 4.53 3D model © BEAR-iD Architecture

Configuration modules BIPV

System definition					System data				
System	Solar field	SubSystem	Orient (º)	Tilt (º)	N. mod H	N. mod V	Total N. mod	Total area (m2)	Total power (kWp)
Demo 5	S façade	CSF	0	0	8	14	112	132,5	17,0

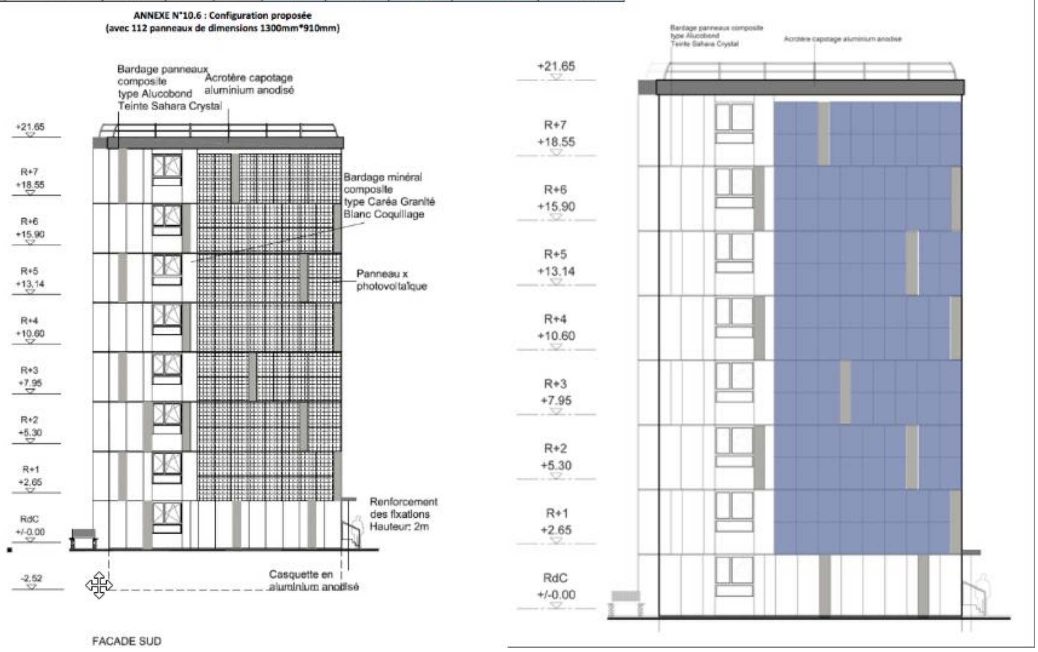


Figure 4.54 Architectural/Installation specifications to BIPV layout from VILOGIA

Figure 4.55 Importation of the 3D model into PVSITES. METEONORM® TM2 weather data

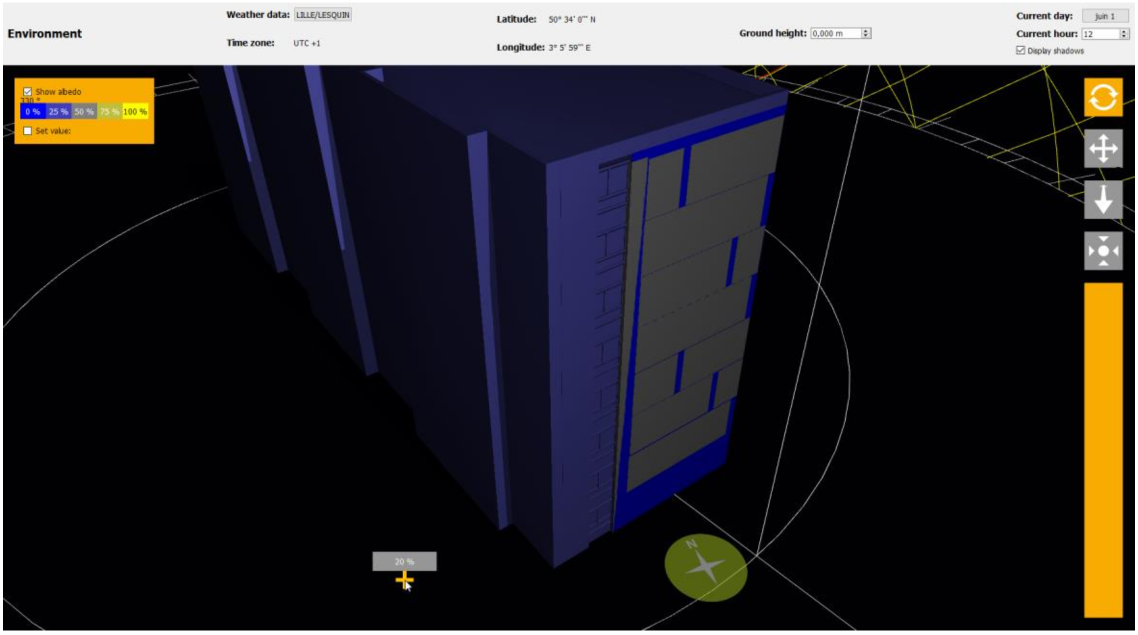


Figure 4.56 Albedo settings: common meadows for surroundings

PHOTOVOLTAIC GLASS	1300 x	910
	6" Mono	Crystalline
Electrical data test conditions (STC)		
Nominal peak power	151	P_{mpp} (Wp)
Open-circuit voltage	22.22	V_{oc} (V)
Short-circuit current	9.05	I_{sc} (A)
Voltage at nominal power	18.34	V_{mpp} (V)
Current at nominal power	8.26	I_{mpp} (A)
Power tolerance not to exceed	±10	%
STC: 1000 w/m², AM 1.5 and a cell temperature of 25°C, stabilized module state.		
Mechanical description		
Length	1300	mm
Width	910	mm
Thickness	13.8	mm
Surface area	1.18	sqm
Weight	35.49	Kgs
Cell type	6" Mono	Crystalline
No PV cells / Transparency degree	35	0% (Opaque)
Front Glass	6 mm	PPI Black connections
Rear Glass	6 mm	Tempered Glass+Black frit
Thickness encapsulation	1,80 mm	EVA Foils
Category / Color code		
Junction Box		
Protection	IP65	
Wiring Section	2,5 mm² or	4,0 mm²
Limits		
Maximum system voltage	1000	Vsys (V)
Operating module temperature	-40…+85	°C
Temperature Coefficients		
Temperature Coefficient of Pmpp	-0,451	%/°C
Temperature Coefficient of Voc	-0,361	%/°C
Temperature Coefficient of Isc	+0,08	%/°C

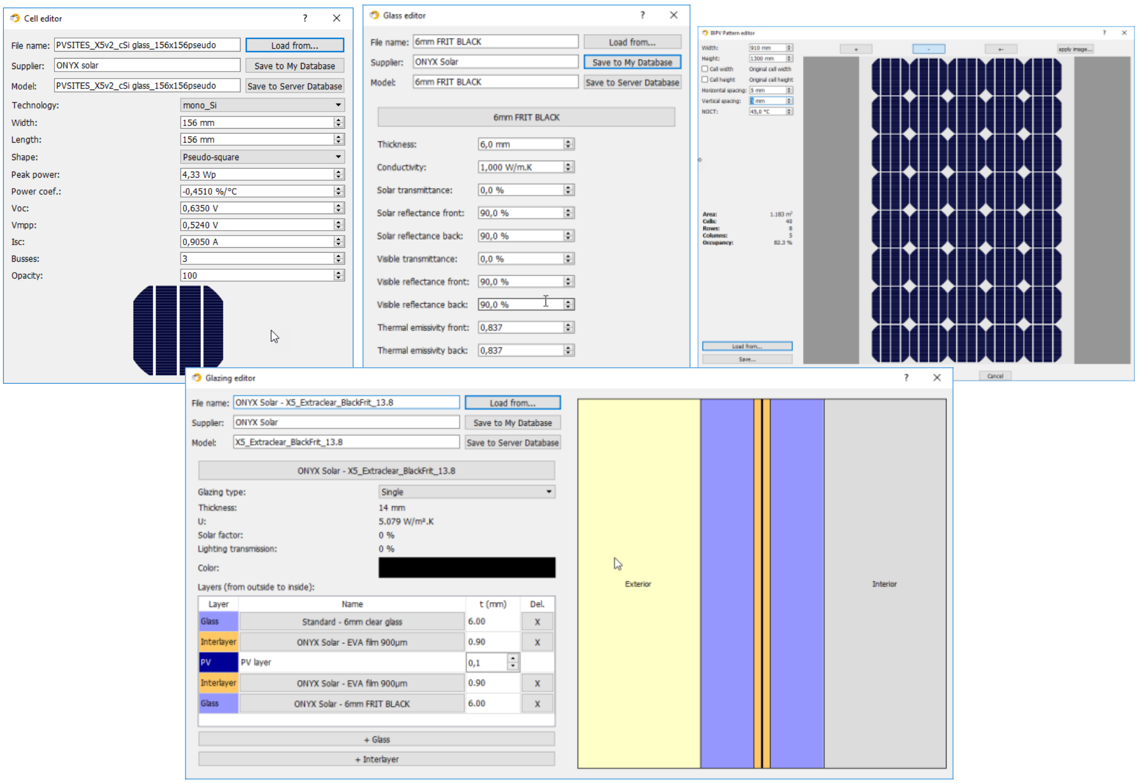


Figure 4.57 151Wp 910x1300 "X5" modules from ONYX Solar: glass/glass, black ribbons, hidden busbars; opaque BIPV strategy for simulation from manufacturer datasheet (latest X5 product version)

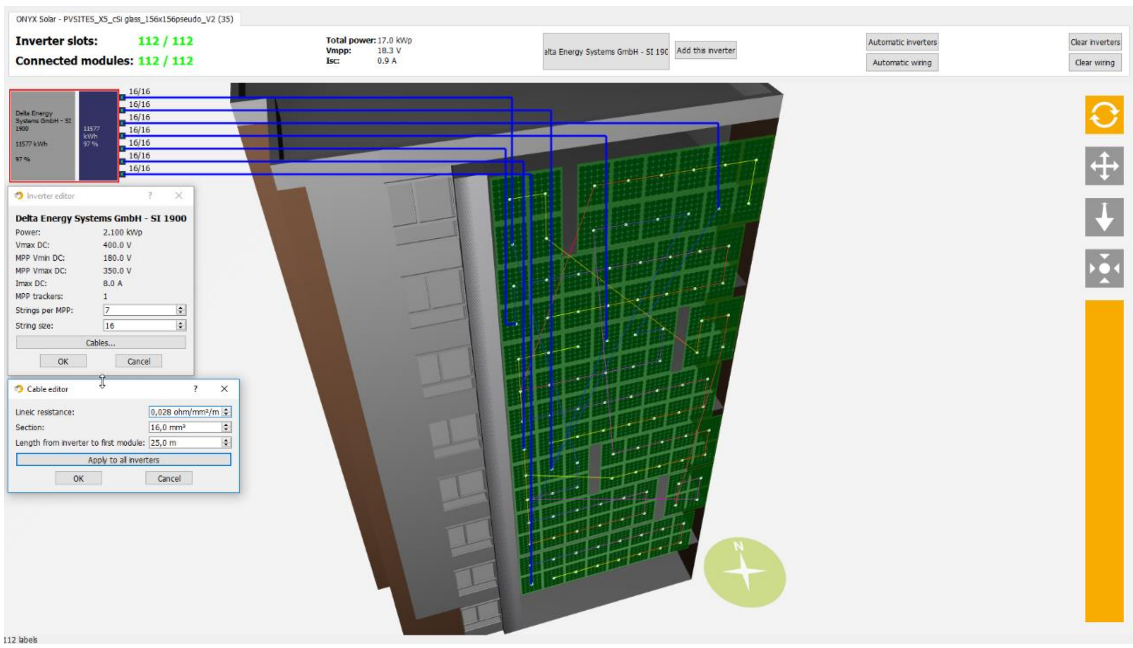


Figure 4.58 BoS strategy: common inverter with single MPP tracker selected from PHOTON© database before definitive settings from partners

4.6.2 Results

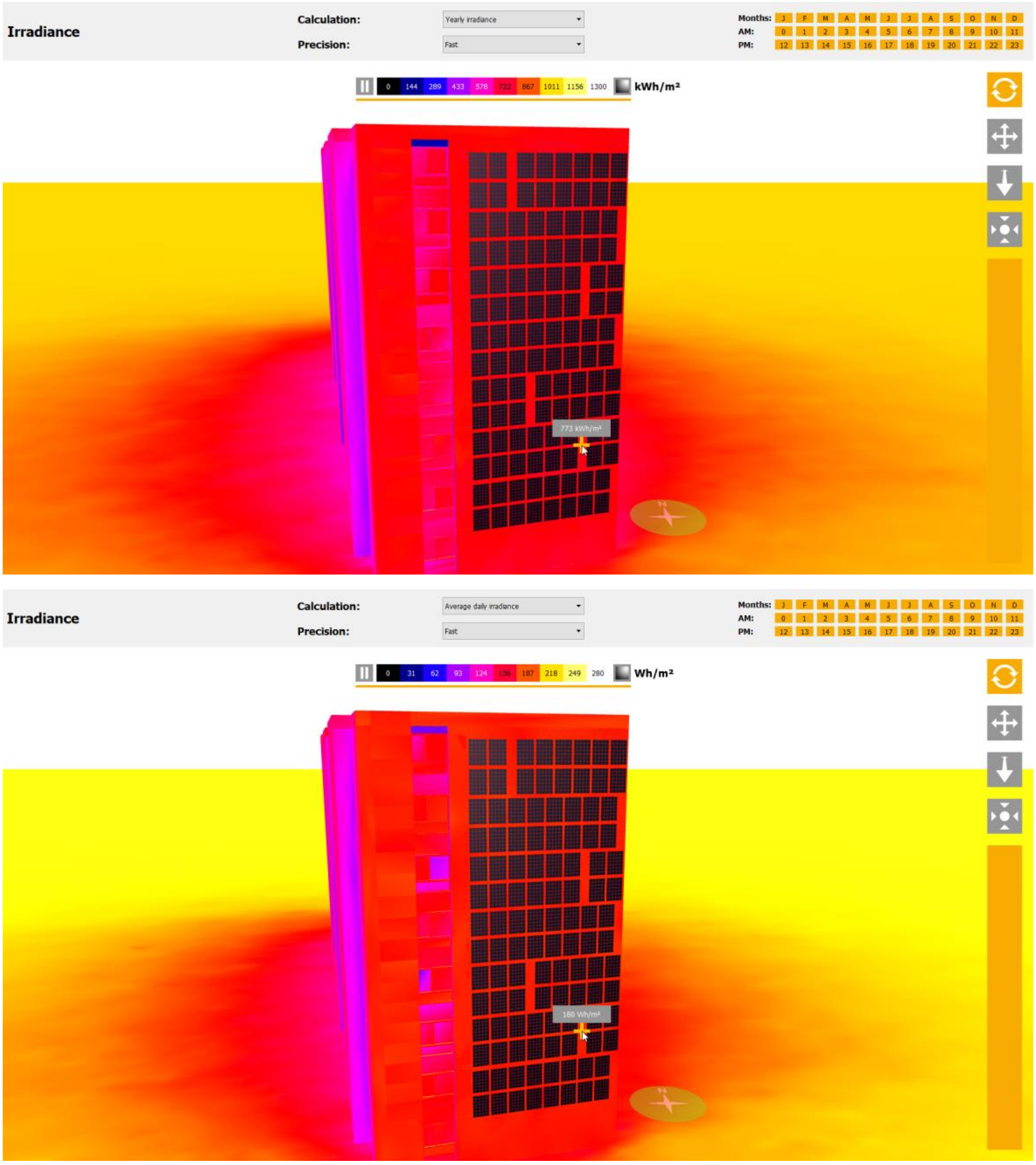


Figure 4.59 Yearly irradiance (773kWh/m2), average daily irradiance (180Wh/m2). Poor irradiance due to location (weather data)

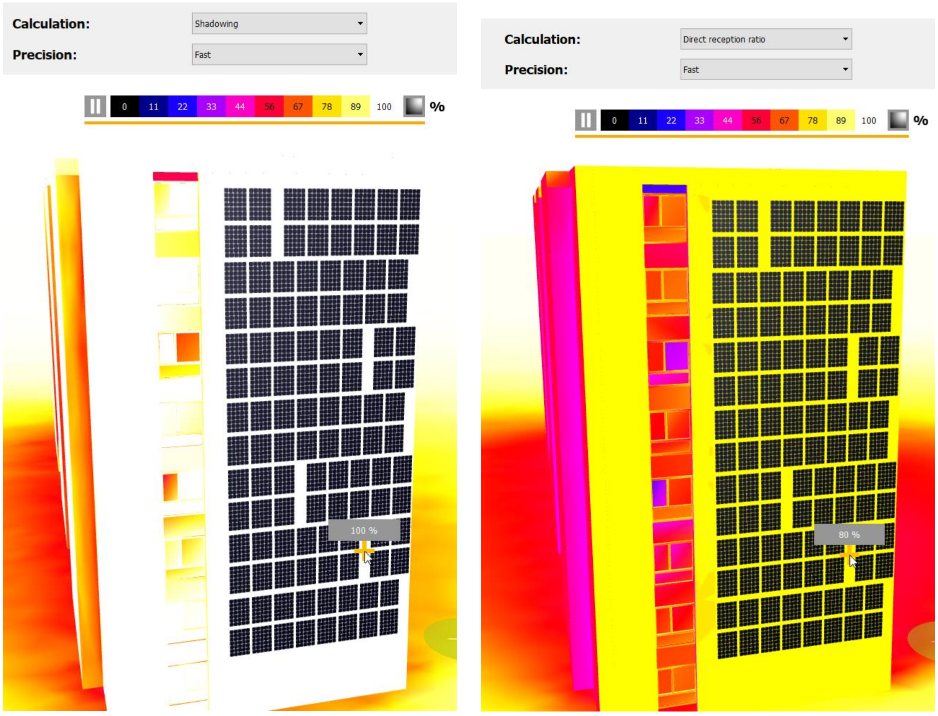


Figure 4.60 No shadowing - 80% direct reception

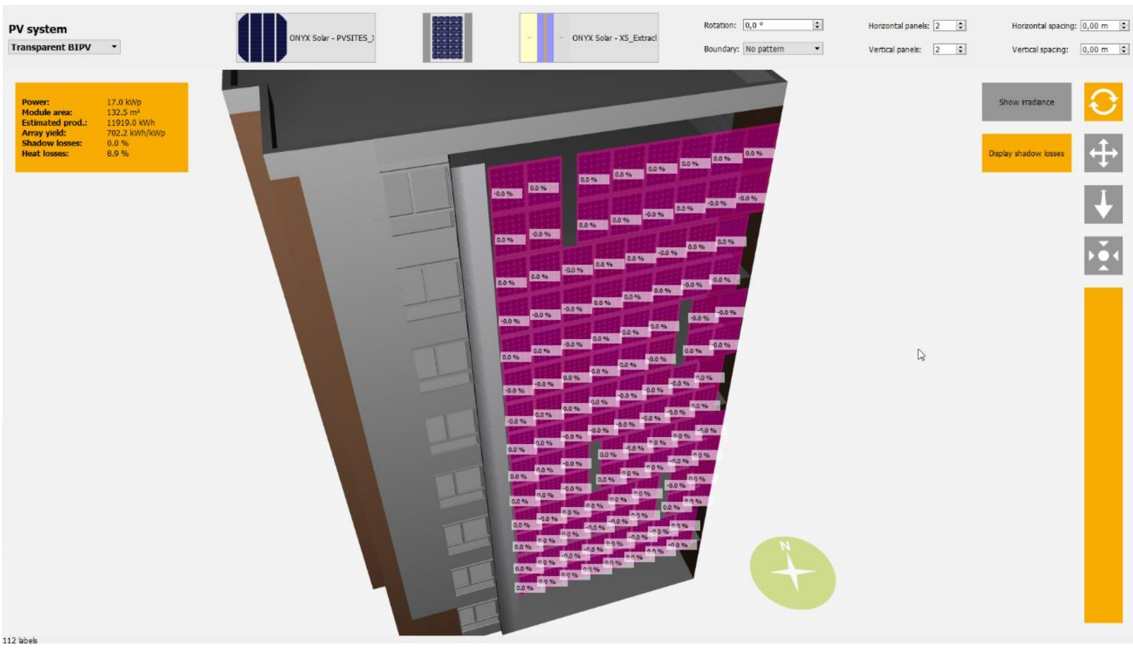


Figure 4.61 Production of the PV system. KPIs: Power=17kWp (132.5sqm); Array yield=702kWh/kWp; Total production=11,919kWh/y; no shadowing losses; typical heat losses (8.9%)

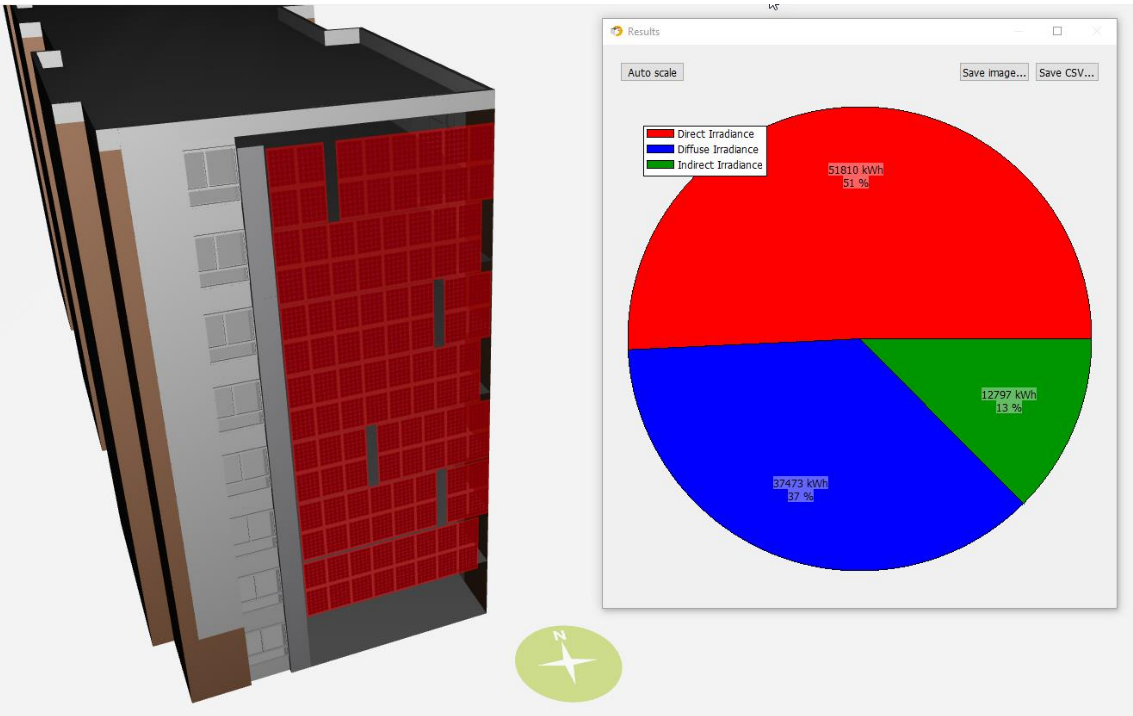


Figure 4.62 Irradiance: highlighting the share between direct (sun), indirect (albedo) and diffuse gains (sky). The role of the albedo is prominent in this case

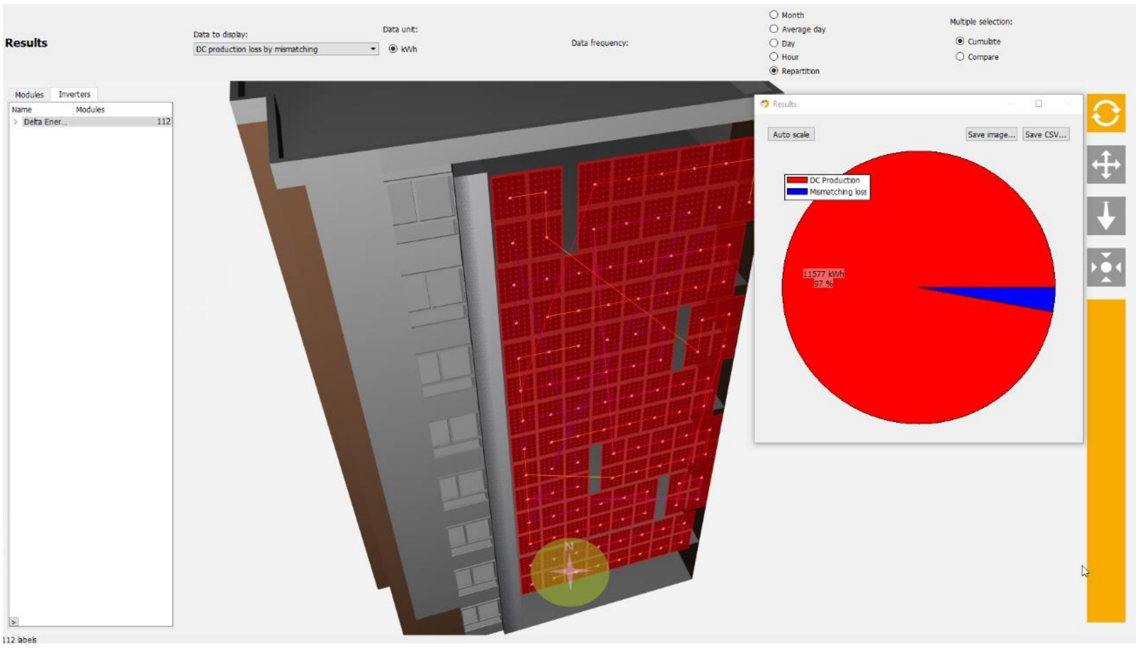


Figure 4.63 Production from VILLOGIA's façade, inverter DC output. 11,577kWh distributed from yearly to hourly time step; csv exportation to downstream processing (PVSITES planning tool)

4.6.3 Conclusions

VILLOGIA building's facade was supposed to be the better location for PV production in this area, roofing excluded. Our simulations confirm these assumptions but array yield is poor in this location: 702kWh/kWp.

Reflected (indirect) irradiance generated from albedo effect (close surroundings) has to be considered as a valuable asset.

Heat losses are typical (8.9%) for c-Si technology. This prediction has to be challenged by measurement in real conditions for these new modules and our thermal models could be improved.

At the current stage of the performance validation of the software and provided the fact that products and project are submitted to updates we consider that the first results are realistic and we did not face critical difficulties in the process. Next step will be comparison between measurement and simulation as soon as the modules will be integrated. Thermal impact will be also implemented.

4.7 DEMO#6 – TECNALIA building, simulation by PVSITES BIPV modelling tool

4.7.1 Hypothesis

Figure 4.64 Modelling has been made as much realistic as it could be from the owner (TrimbleTM SketchUpTM model). Surroundings have not been drawn but are considered as non-significant for simulation, except types of surfaces for albedo effects

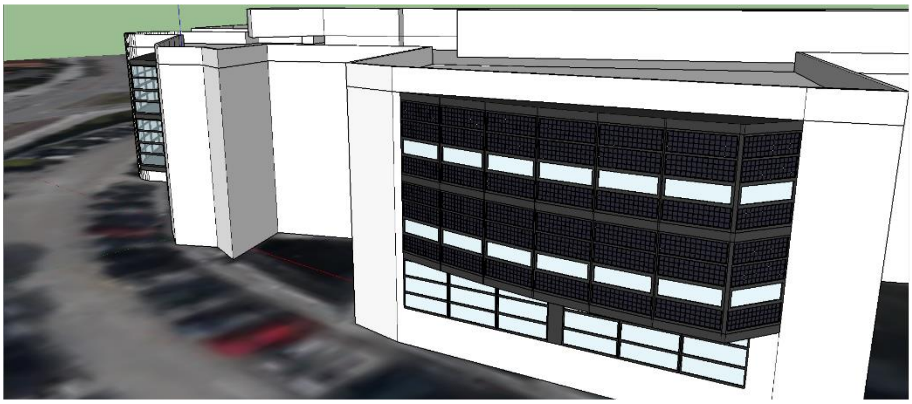


Figure 4.65 3D model from the architect. To be updated (BIPV layouts have changed)

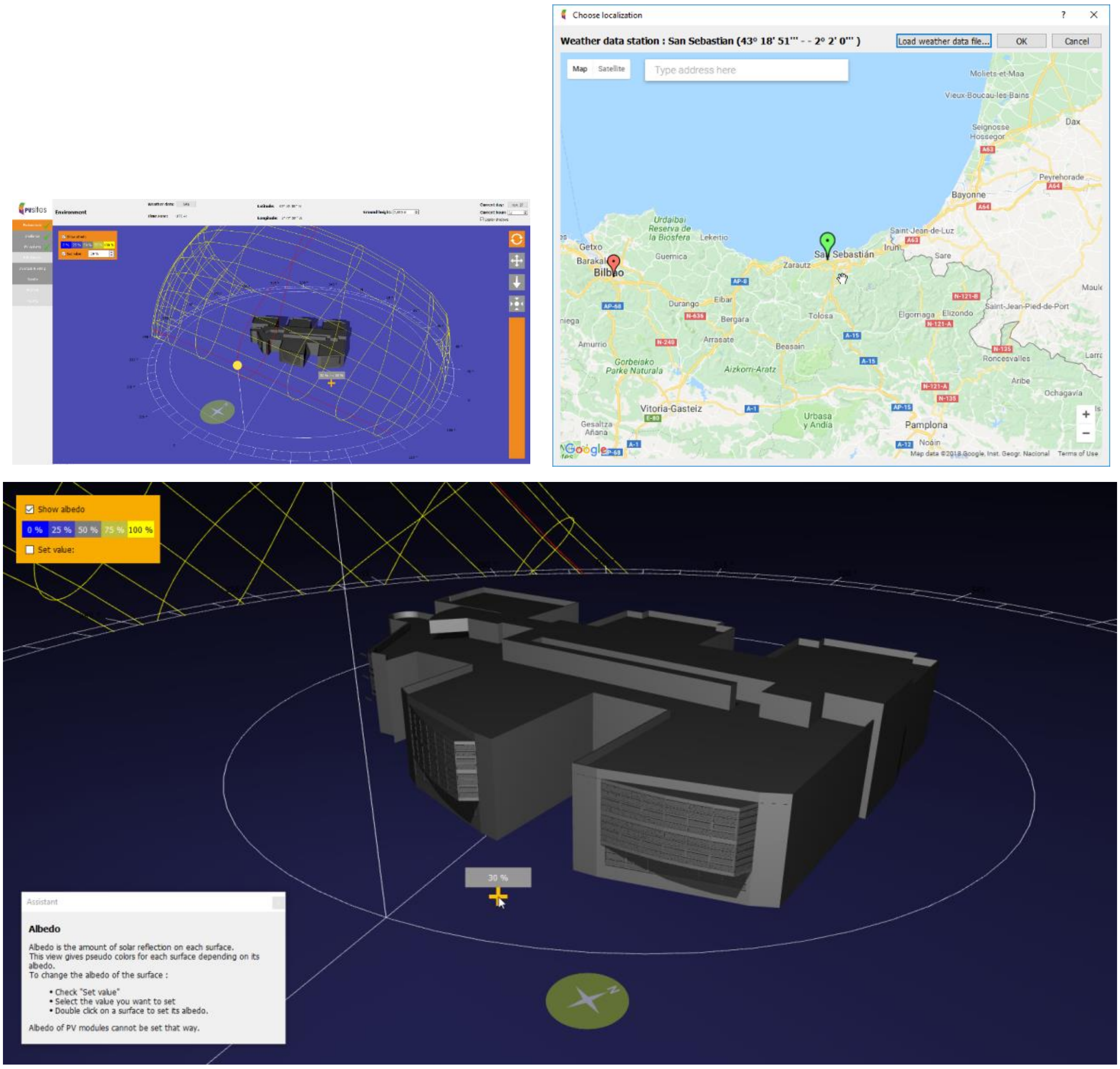
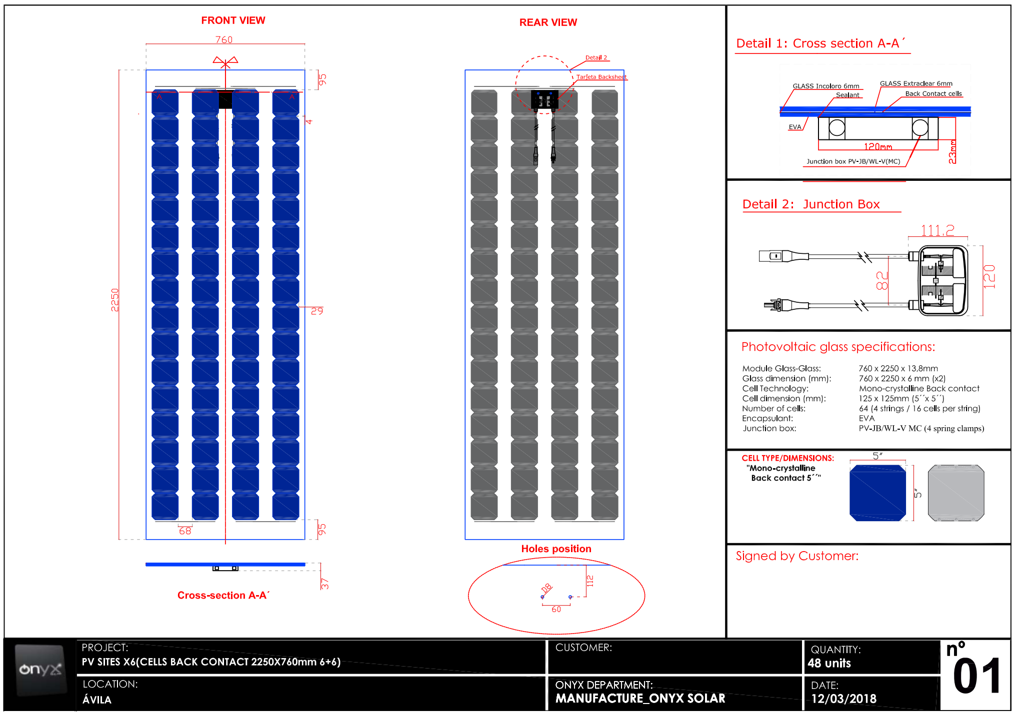
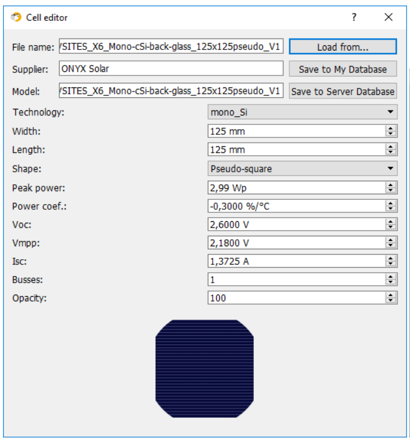
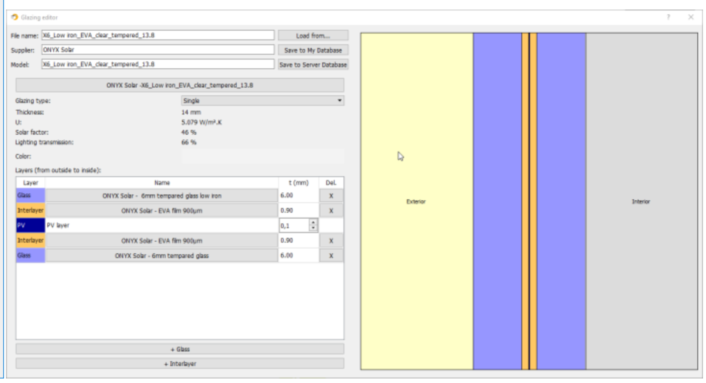
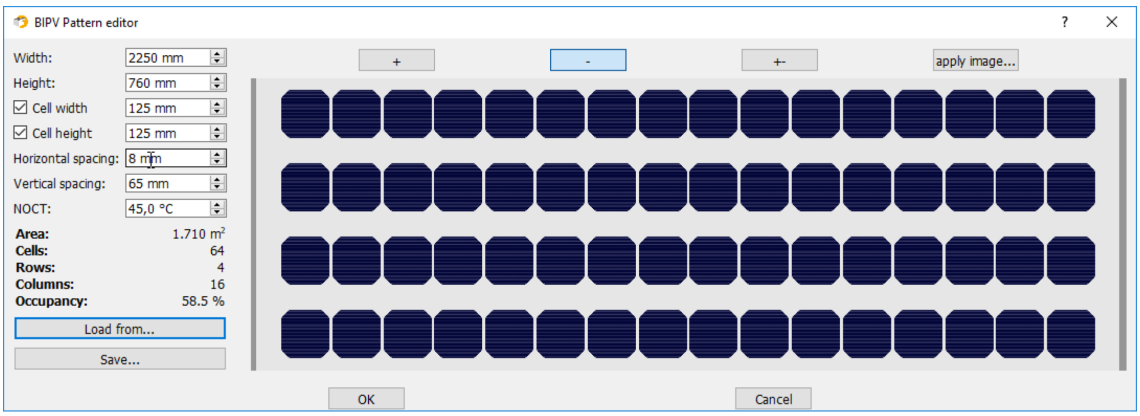


Figure 4.66 Importation of the 3D model into PVSITES. METEONORM® TM2 weather data at closest location. Albedo 30% on surroundings (clear ground)


FRONT VIEW
REAR VIEW
760
2250
Cross-section A-A´
Holes position
Detail 1: Cross section A-A´
GLASS Incoloro 6mm
Sealant
GLASS Extraclear 6mm
Back Contact cells
EVA
120mm
Junction box PV-JB/WL-V(MC)
23mm
Detail 2: Junction Box
111,2
82
120
Photovoltaic glass specifications:
Module Glass-Glass: 760 x 2250 x 13,8mm
Glass dimension (mm): 760 x 2250 x 6 mm (x2)
Cell Technology: Mono-crystalline Back contact
Cell dimension (mm): 125 x 125mm (5´´x 5´´)
Number of cells: 64 (4 strings / 16 cells per string)
Encapsulant: EVA
Junction box: PV-JB/WL-V MC (4 spring clamps)
CELL TYPE/DIMENSIONS:
"Mono-crystalline Back contact 5´´"
Signed by Customer:
onyx
PROJECT:
PV SITES X6(CELLS BACK CONTACT 2250X760mm 6+6)
LOCATION:
ÁVILA
CUSTOMER:
ONYX DEPARTMENT:
MANUFACTURE_ONYX SOLAR
QUANTITY:
48 units
DATE:
12/03/2018
nº 01


Cell editor
File name: /SITES_X6_Mono-cSi-back-glass_125x125pseudo_V1
Load from...
Supplier: ONYX Solar
Save to My Database
Model: /SITES_X6_Mono-cSi-back-glass_125x125pseudo_V1
Save to Server Database
Technology: mono_Si
Width: 125 mm
Length: 125 mm
Shape: Pseudo-square
Peak power: 2,99 Wp
Power coef.: -0,3000 %/°C
Voc: 2,6000 V
Vmpp: 2,1800 V
Isc: 1,3725 A
Busses: 1
Opacity: 100




BIPV Pattern editor
Width: 2250 mm
Height: 760 mm
Cell width 125 mm
Cell height 125 mm
Horizontal spacing: 8 mm
Vertical spacing: 65 mm
NOCT: 45,0 °C
Area: 1.710 m²
Cells: 64
Rows: 4
Columns: 16
Occupancy: 58.5 %
Load from...
Save...
+
-
+-
apply image...
OK
Cancel

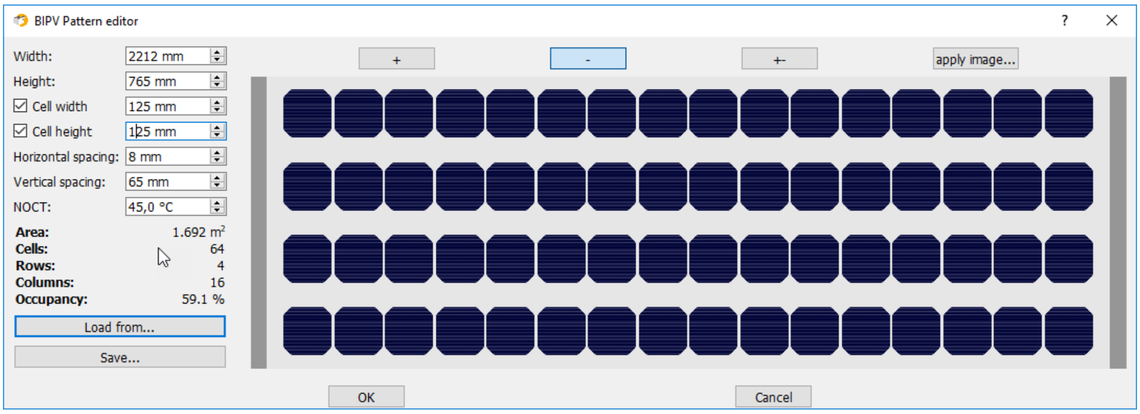
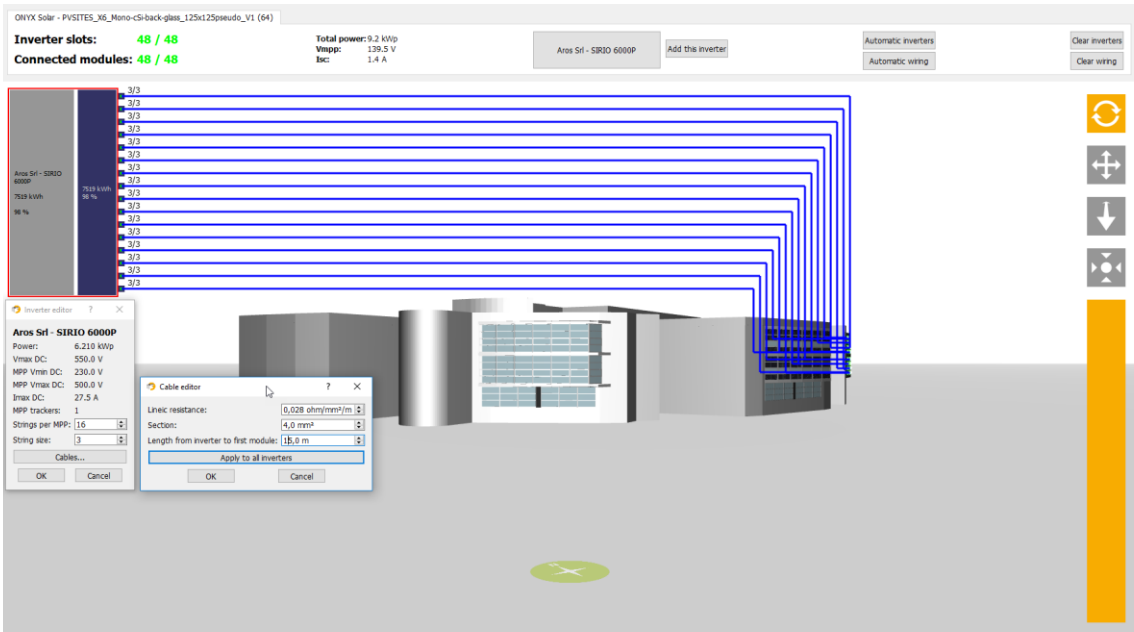


Figure 4.67 191.5Wp "X6" modules from ONYX Solar datasheets: back contact pseudo-square c-Si cells; 6mm glass/glass/EVA; Transparent BIPV strategy for simulation with exact overall dimensions; cell arrangement to be improved



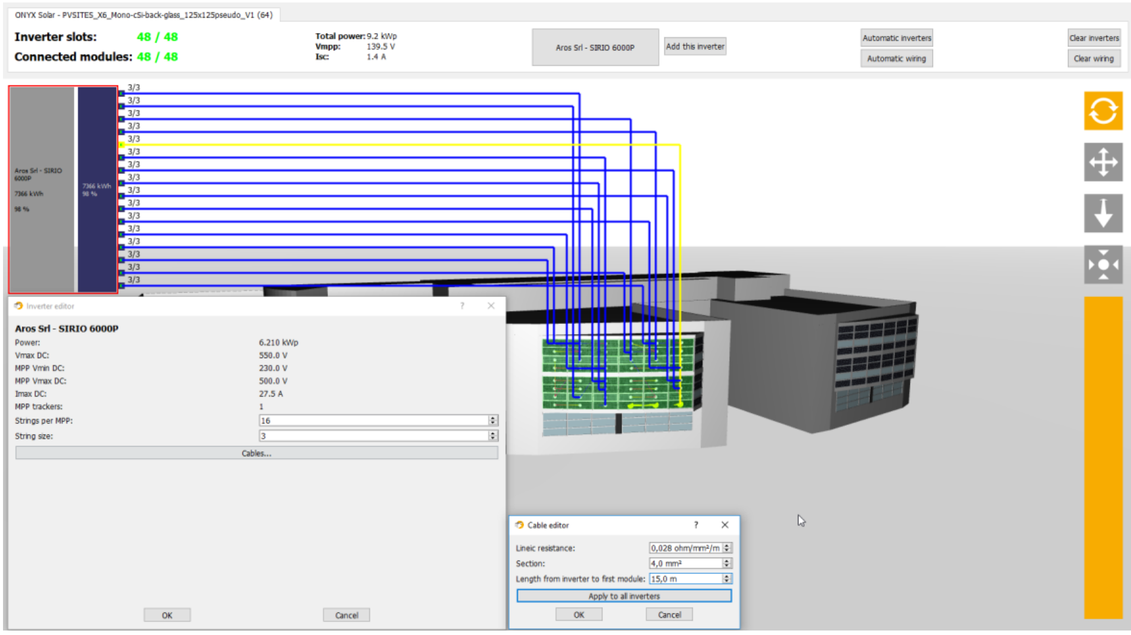


Figure 4.68 BoS strategy: common inverter with single MPP tracker selected from PHOTON© database before definitive settings from partners

4.7.2 Results

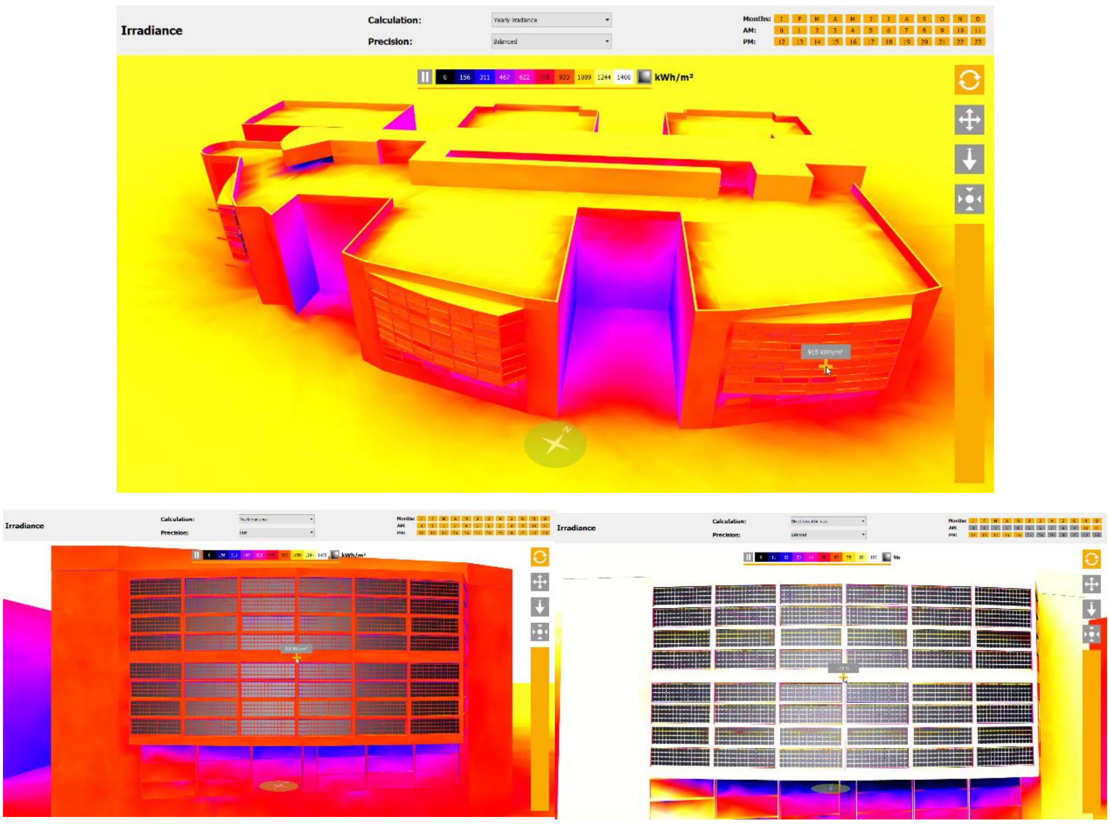


Figure 4.69 Yearly irradiance: shadowing losses=none; correct irradiance on both facades; 100% direct reception between 10AM and 4PM: sun protection validated

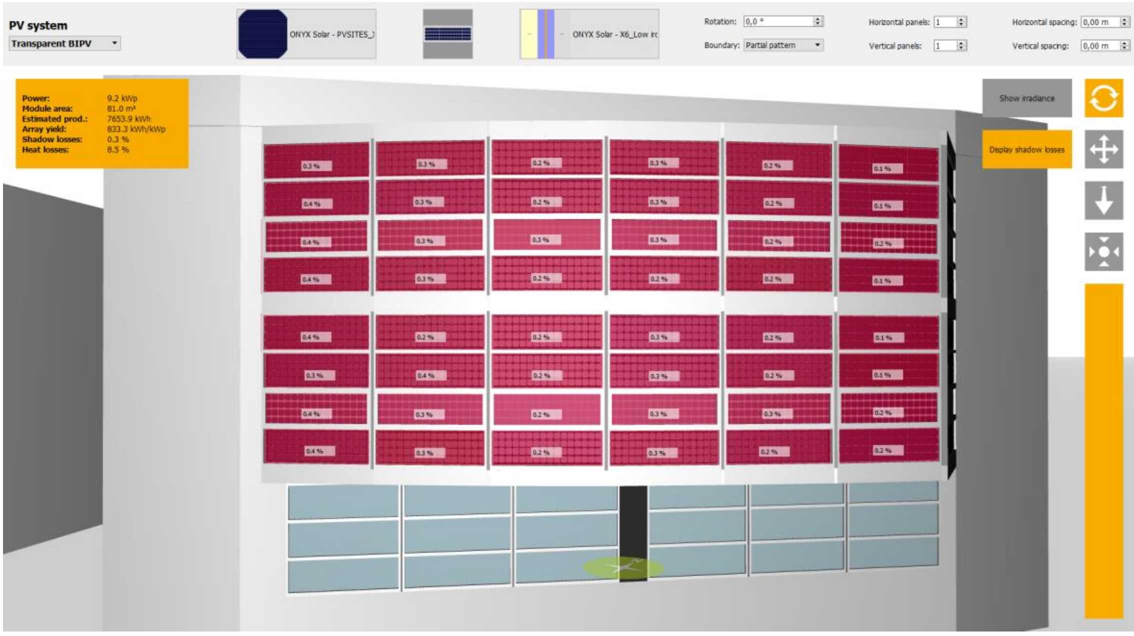


Figure 4.70 BIPV patterns on East (B) facade; occupancy 59% → transparency 41%; KPIs: Power=9.2kWp (81sqm); Array yield=833kWh/kWp; Total production=7,654kWh/y; no shadowing losses; typical heat losses (8.5%)

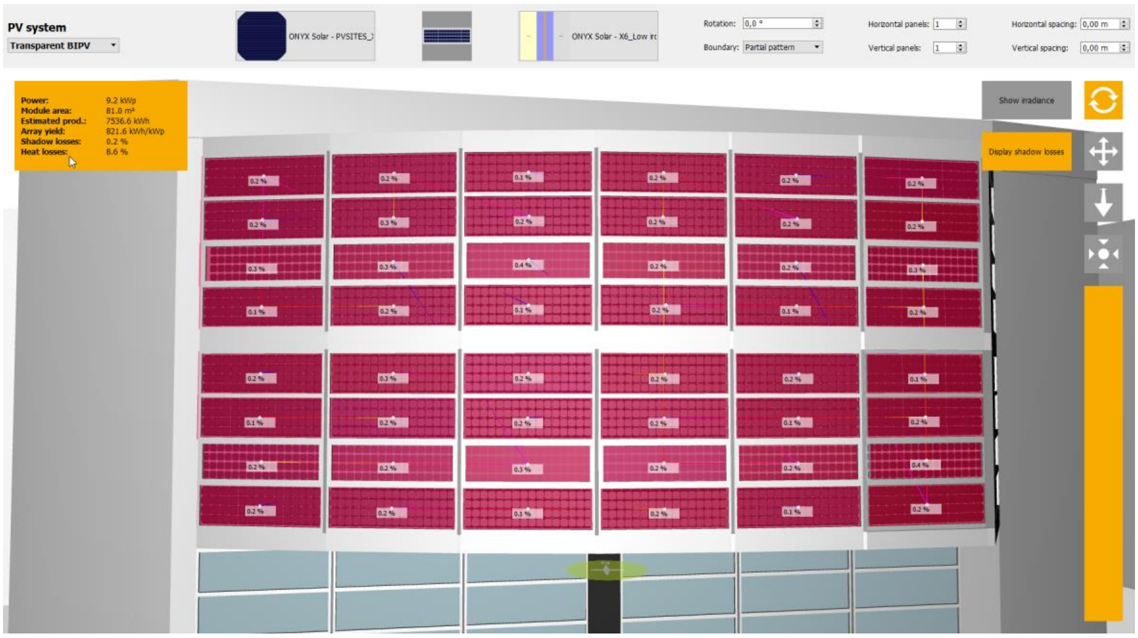


Figure 4.71 BIPV patterns on South (A) facade; occupancy 59% → transparency 41%; KPIs: Power=9.2kWp (81sqm); Array yield=822kWh/kWp; Total production=7,537kWh/y; no shadowing losses; typical heat losses (8.6%)

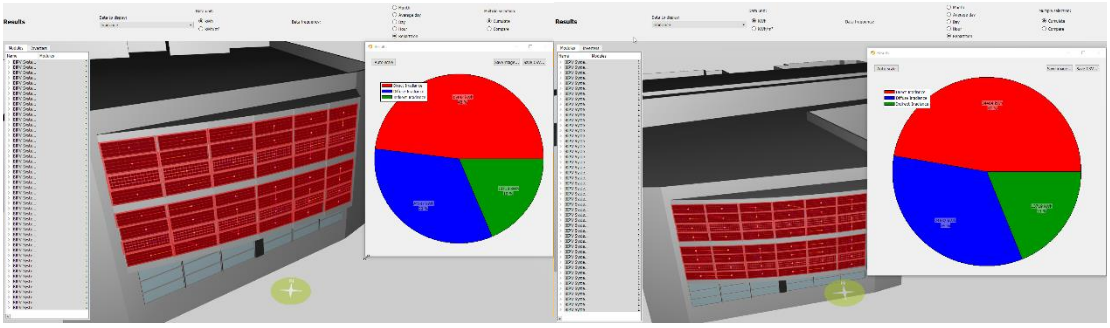
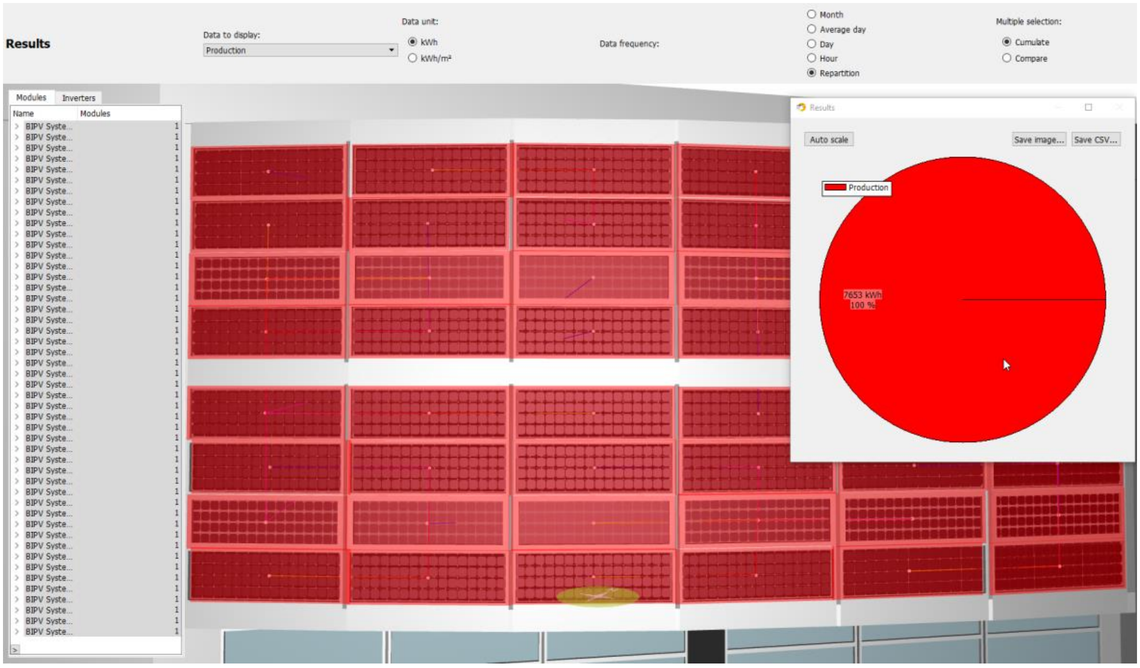


Figure 4.72 Irradiance: highlighting the share between direct (sun), indirect (albedo) and diffuse gains (sky). The role of the albedo is prominent in this case (19%)



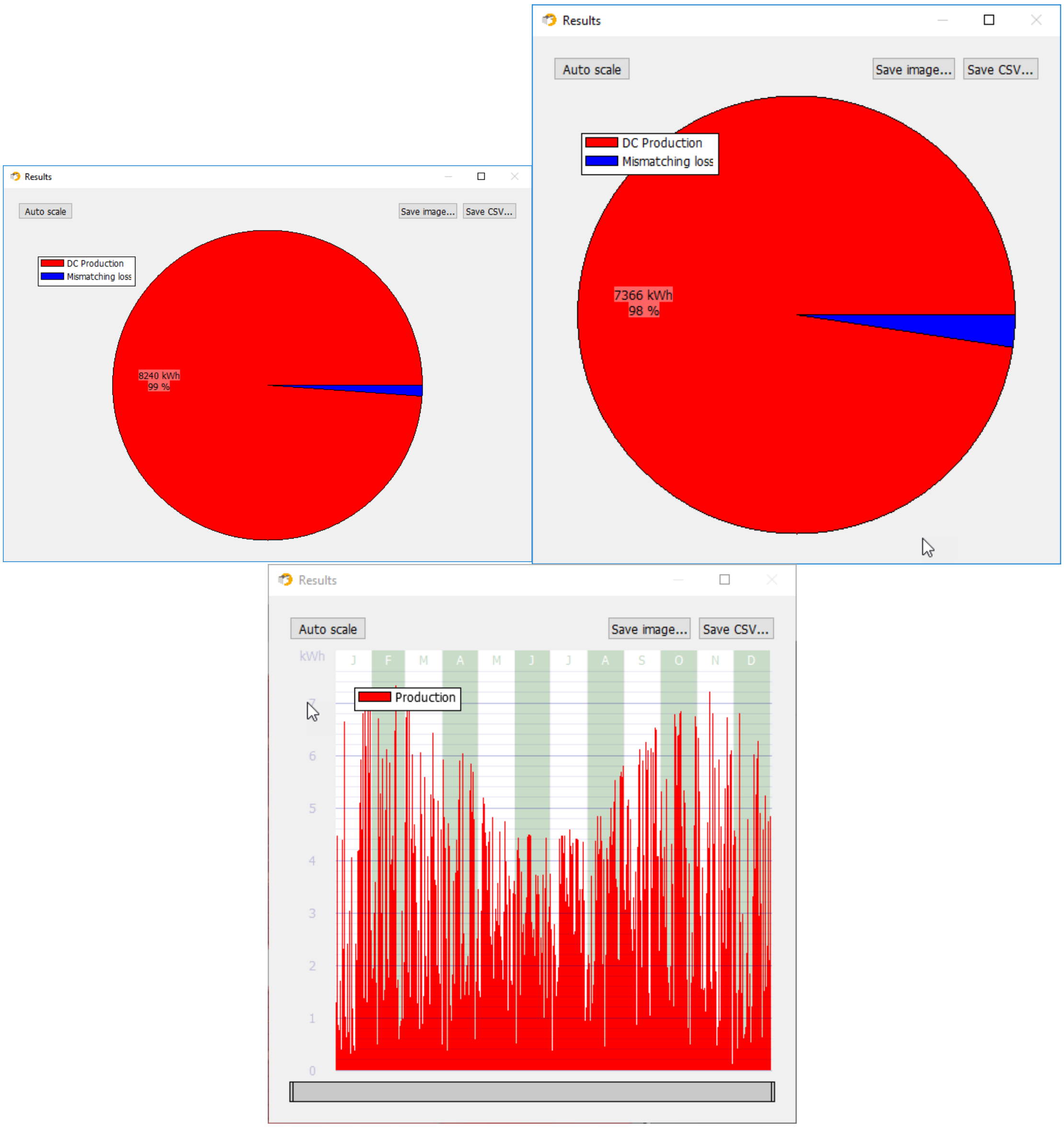


Figure 4.73 Array Production and DC inverter production for TECNALIA building's facades. 7,366kWh + 8,240 kWh distributed from yearly to hourly time step; csv exportation to downstream processing (PVSITES planning tool); highlighting January, February + November peaks and seasonal variations

4.7.3 Conclusions

TECNALIA's south facades were supposed to be the better location for PV production in this area, roofing excluded. Our simulations confirm these assumptions. Array yield is correct in this location: around 830kWh/kWp.

Reflected (indirect) irradiance generated from albedo effect (close ground, bright) has to be considered as a valuable asset: 19%.

Heat losses are typical (8.5%) for c-Si technology. This prediction has to be challenged by measurement in real conditions for these new modules and our thermal models could be improved.

At the current stage of the validated performance of the software, with transparent BIPV strategy chosen for simulation, and provided the fact that products and project are submitted to updates we consider that the first results are realistic and we did not face critical difficulties in the process. Next step will be comparison between measurement and simulation as soon as the modules will be integrated. Thermal impact will be also implemented.

5 DEMO-SYSTEMS SIMULATION BY PVSITES PLANNING TOOL

After evaluating BIPV generation potential in every demo site by means of PVSITES BIPV modelling tool, simulation and analysis on energy use of this BIPV generation has been carried out by means of the planning tool developed by TECNALIA in the task T6.1. As a result, the fittest BIPV and storage capacities, as well as the most suitable operating energy management strategy for every demo system, based on energy and economic criteria, have been deduced from the simulation results.

5.1 Simulation methodology by PVSITES planning tool

The proposed methodology for this analysis on energy use of BIPV generation in every demo site consists of the following stages:

a. Determination of initial hypothesis, defining the inputs required by PVSITES planning tool:

    I. BIPV generation profile. This has been directly obtained from the BIPV modelling simulation results described in the previous section. If BIPV generator capacity can be increased within existing architectonical constraints, it has been also considered.

    II. Building electrical consumption profile. This can be based on historical data collected for a whole year, deduced from partial monitoring data or estimated in case of future consumptions.

    III. Economic conditions are based on current electricity bills (taxes excluded) and local conditions for BIPV, though eluding any kind of BIPV supporting scheme, like net-metering or Feed-in-Tariff (FiT), that are supposed to be suppressed in the short term.

    IV. Characterization of BIPV and storage technologies. This information is extracted from datasheets provided by BIPV and battery manufacturers. It is important to note that BIPV generation costs are based on PVSITES manufacturers projections, since actual costs of PVSITES prototypes are quite higher. Similarly, storage costs have been estimated considering current prices of industrialized commercial solutions for PV applications (taxes excluded), but not directly from quotations of battery packs for PVSITES project, since these are high-priced customized solutions. Unless other consideration specified, the following storage parameters have been assumed for all the demo sites.

Table 5.1 Considered storage technology parameters

Parameter	Unit	Value
Calendar life	years	15
Number of cycles @80% DoD	-	3,000
Charge efficiency	%	98
Discharge efficiency	%	98
CAPEX	€/kWh	500
Annual OPEX	€/kWh	0

V. Financial parameters. Unless other consideration specified, a discount rate of 2% is considered for the financial calculations. Neither increase of electricity tariffs nor reduction of storage costs for replacement are not considered.

b. PVSITES planning tool carries out a parametric analysis running energy simulations for a whole year under different scenarios of PV and storage capacities and energy management strategies.

c. Results are examined to select the best BIPV + storage system solution according to economic criteria, determining PV and storage capacities and energy management strategy.

5.2 DEMO#1 – FormatD2 house, simulation by PVSITES planning tool

5.2.1 Hypothesis

The initial assumptions for DEMO#1 – FormatD2 house have been:

a. BIPV generation profile. This has been directly obtained from the BIPV modelling simulation results described in the section 4.2.2. Since BIPV generator capacity (8,640Wp) is given by the roof surface (105.5m^2), other alternatives have been discarded. Expected annual energy yield at the DC input of the inverter is 8,045kWh.

b. Building electrical consumption profile. This house is equipped with a complete monitoring system collecting data of disaggregated consumption every ten minutes. The monitoring data from 2016 have been used to generate the annual consumption profile on hourly basis. The annual electricity consumption is 6,784kWh.

c. Economic conditions. Electricity provider in Demo#1-FORMATD2 house is Luminus. The annual electricity bill reaches 1,348€, as the sum of a fixed term of 79.65 €/year for meter fee and counter leasing and a variable term depending on measured consumption and the electricity tariffs gathered in the following table. PV excess is neither considered to be remunerated nor compensated through net-metering, as stated for installations later than June 2018.

Table 5.2 Electricity tariffs for DEMO#1 – FORMATD2 house

Period	Time range	Price (€/kWh, tax 21% excluded)
Day	From 7h to 22h	21.7615
Night (Weekend)	From 22h to 7h (From Friday at 22h to Monday at 7h)	15.9415

d. BIPV generator cost. CIGS BIPV module shows an efficiency of 108W/m^2 and its price is projected to be 100€/m^2 by year 2021, according to PVSITES targets. Considering 50€/m^2 as the cost for conventional tiles, over cost due to the BIPV modules is supposed to be 50€/m^2. PV storage inverter price is projected to be 1,600€ without the battery pack. The rest of installation and commissioning costs are supposed to be 0,3€/Wp, resulting in a total over cost of 0.92€/Wp.

5.2.2 Results

In the following table, main results from PVSITES planning tool are presented for different storage capacities scenarios.

Table 5.3 PVSITES planning tool main results for DEMO#1 – FORMATD2 house

Storage capacity	Self-consumption rate	Autarchy	CAPEX	Annual saving	Payback period
-	31.4%	37.4%	7,949€	500.8€	20 years
2kWh	38%	45.3%	8,949€	568.7€	24 years
4kWh	43.1%	51.4%	9,949€	651.2€	24 years
6kWh	47.1%	56.2%	10,949€	713,5€	26 years
8kWh	49.8%	59.3%	11,949€	751.8€	29 years
10kWh	51.1%	60.9%	12,949€	771,2€	29 years

5.2.3 Conclusions

BIPV generator payback period is 20 years if only incomes coming from electricity savings are considered. Main reasons are scarce solar resource (around 1kWh/m^2) and low direct self-consumption rate (31.4%). A storage system of 10kWh can be used to reach quite higher self-consumption rate (51.1%) and autarchy (60.9%). However, this increases payback period mainly due to the difficulties to get additional revenues from it apart from increasing self-consumption rate. In fact, it is not possible to take great advantage from electricity tariff variability since it remains constant during daytime.

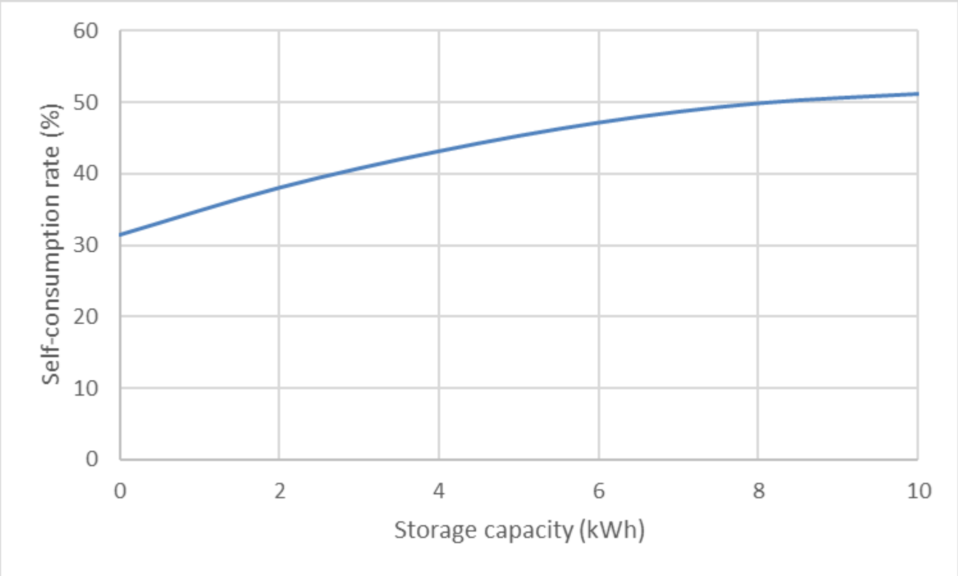


Figure 5.1 Estimated self-consumption rate for DEMO#1 as a function of installed storage capacity

Advanced energy management strategy allows to reduce more than 40% peak power consumed from the grid, with a storage capacity of at least 4kWh. Although this peak-shaving is not currently remunerated in Belgium, it will help to grid planning and operation.

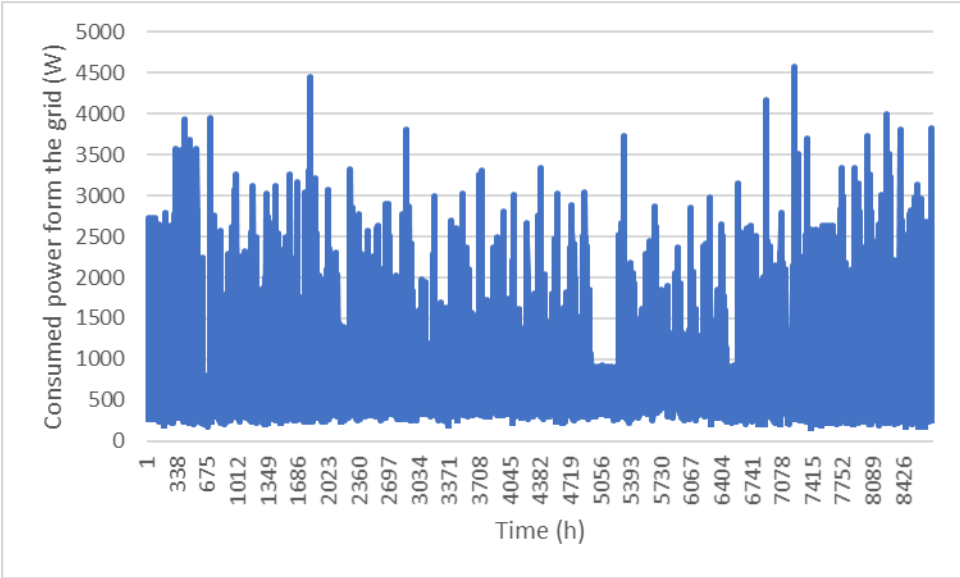


Figure 5.2 Yearly consumption on hourly basis for DEMO#1. Power peak reaches 4.5kW

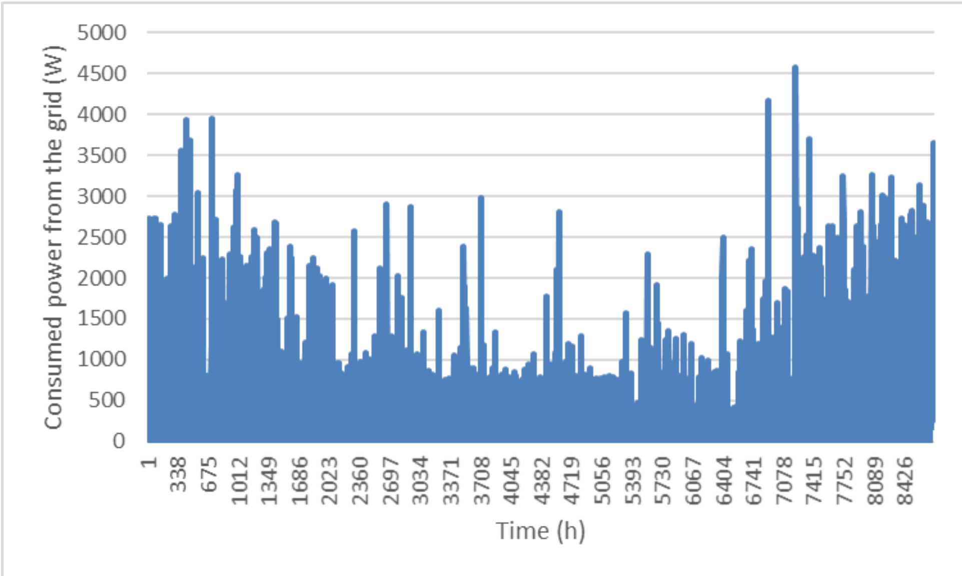


Figure 5.3 Consumption from the grid with BIPV generator and storage capacity of 10kWh with a conventional energy management strategy for DEMO#1. Power peak remains above 4.5kW

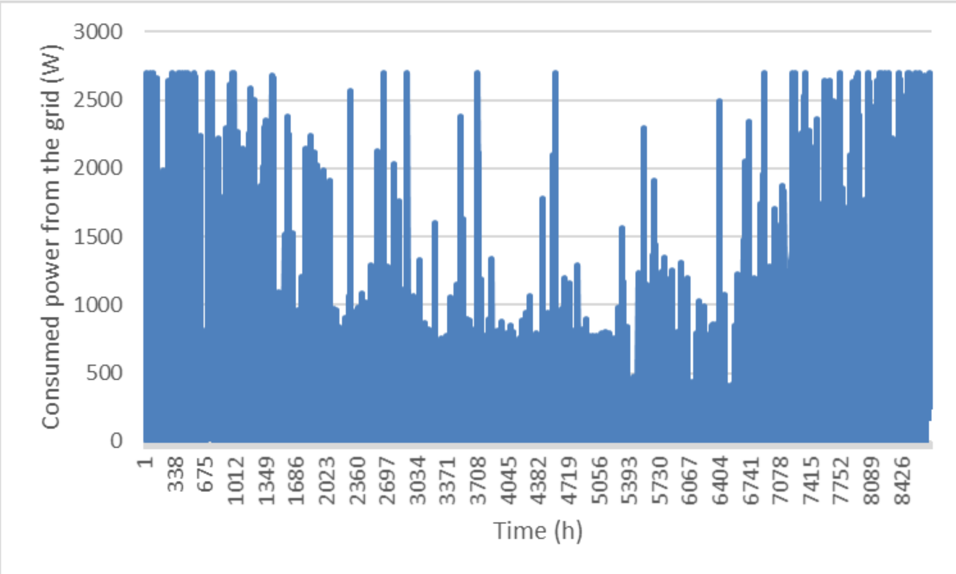


Figure 5.4 Consumption from the grid with BIPV generator and storage capacity of 10kWh with PVSITES predictive energy management strategy for DEMO#1. Power peaks are reduced to 2.7kW

5.3 DEMO#2 – EHG, simulation by PVSITES planning tool

5.3.1 Hypothesis

The initial assumptions for DEMO#2 – EHG have been:

a. BIPV generation profile. This has been directly obtained from the BIPV modelling simulation results described in the section 4.3.2. Since BIPV generator capacity (7,040Wp) is given by the available surface in West and East facades of pavilions 1 and 2, respectively, other alternatives have been discarded. Expected annual energy yield is 3,982kWh.

b. Building electrical consumption profile. This installation is equipped with a general electricity meter collecting consumption data every fifteen minutes. The monitoring data from 2015 have been used to generate the annual consumption profile on hourly basis. Since consumption is quite higher than expected BIPV generation, only consumption associated to the pavilions where the BIPV generator is going to be installed has been considered. This consumption has been estimated proportionally estimated to area of these pavilions. Despite considering only this portion of the global consumption, the annual electricity consumption is 177,720kWh.

c. Economic conditions. Analyzing historical electricity tariffs, it can be concluded that the average price of electricity is around 20c€/kWh, considering CHF/EUR exchange rate of 0.86.

d. BIPV generator cost. CIGS BIPV module shows an efficiency of 80W/m^2 and its price is projected to be 100€/m^2 by year 2021, according to PVSITES targets. Rest of installation and commissioning costs are supposed to be 0,4€/Wp, including PV inverter cost.

5.3.2 Results

In the following table, main results from PVSITES planning tool are presented. As there is no PV excess, neither storage capacity nor advanced EMS has been considered.

Table 5.4 PVSITES planning tool main results for DEMO#2 – EHG

Storage capacity	Self-consumption rate	Autarchy	CAPEX	Annual saving	Payback period
-	100%	2.24%	11,616€	796.4€	18 years

5.3.3 Conclusions

BIPV generator shows a payback period near to 20 years if only incomes coming from electricity savings are considered. The main reason of this underperformance is the orientation of available facades. On the other hand, potential saving due to conventional façade cladding material substitution has been ignored. Neither storage capacity nor advanced EMS makes sense in absence of PV excess.

5.4 DEMO#3 – CARPORTS of EMPA and EKZ facilities, simulation by PVSITES planning tool

5.4.1 Hypothesis

The initial assumptions for DEMO#3 – Carports in EMPA and EKZ facilities have been:

a. BIPV generation profile. This has been directly obtained from the BIPV modelling simulation results described in the section 4.4.2. Since BIPV generator capacities in EMPA (7,000Wp) and EKZ (7,340Wp) are given by the design of carport roof and available surface (92.7m^2 and 103.3m^2, respectively), other alternatives have been discarded. Expected annual energy yield is 6,829kWh and 7,790kWh in EMPA and EKZ, respectively.

b. Building electrical consumption profile. In the case of EMPA, considered consumption is from an EV charger located under the BIPV generator. Although its use is still limited, it is expected to increase from BIPV installation commissioning. Therefore, monitored consumption for 2019 Q2 has been used and replicated to estimate the annual consumption profile. In the case of EKZ, though consumption data are not available, associated building consumption is supposed to be quite higher than expected BIPV generation, ensuring a self-consumption rate of 100%.

c. Economic conditions. Average price of electricity is assumed to be 20c€/kWh.

d. BIPV generator cost. CIGS BIPV generator shows an efficiency of 75W/m^2 and its price is projected to be 100€/m^2 by year 2021, according to PVSITES targets. Considering 50€/m^2 as the cost for a conventional metal roofing material, over cost due to the BIPV generator is supposed to be 50€/m^2. Rest of installation and commissioning costs are assumed to be 0,4€/Wp, including PV inverter cost.

5.4.2 Results

In the following table, main results from PVSITES planning tool are presented for EKZ carport. As there is no PV excess, neither storage capacity nor advanced EMS has been considered.

Table 5.5 PVSITES planning tool main results for DEMO#3 – EKZ carport

Storage capacity	Self-consumption rate	Autarchy	CAPEX	Annual saving	Payback period
-	100%	Data not available	7,829€	1,558€	6 years

In the following table, main results from PVSITES planning tool are presented for EMPA carport, considering different storage capacities scenarios.

Table 5.6 PVSITES planning tool main results for DEMO#3 – EMPA carport

Storage capacity	Self-consumption rate	Autarchy	CAPEX	Annual saving	Power peak reduction
-	21%	13.6%	7,490€	289.3€	0%
2kWh	27.3%	17.6%	8,490€	370.7€	8%
4kWh	31%	20%	9,490€	421€	10%
6kWh	33.7%	21.8%	10,490€	459€	14%
8kWh	35.8%	23.1%	11,490€	487.9€	18%
10kWh	37.4%	24.2%	12,490€	509.9€	22%

5.4.3 Conclusions

In the case of EKZ, a payback period of 6 years is estimated. This is achieved thanks to 100% of self-consumption rate. Neither storage capacity nor advanced EMS makes sense in absence of PV excess.

In the case of EMPA carport, BIPV generator shows a payback period higher than 30 years for all the scenarios. The main reason of this underperformance is the low direct self-consumption rate (21%). Storage increases self-consumption rate and autarchy and reduce required grid power capacity in more than 20% for 10kWh thanks to PVSITES predictive energy management strategy. However, storage increases even more the payback period, since peak-shaving is not remunerated and batteries must be replaced every 15 years. In this application, using directly EV storage capacity would make much more sense if a controllable charging process was feasible. Unfortunately, this is not a straight-forward question as EV are not providing their SoC yet when connection a charging point.

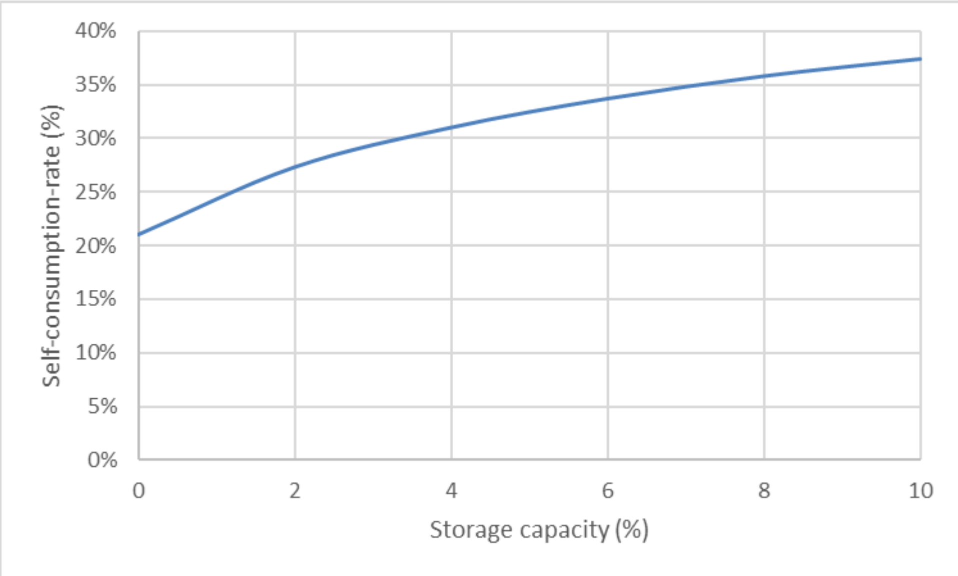


Figure 5.5 Estimated self-consumption rate for DEMO#3 -EMPA carport as a function of installed storage capacity

5.5 DEMO#4 – CRICURSA building, simulation by PVSITES planning tool

5.5.1 Hypothesis

The initial assumptions for DEMO#4 – CRICURSA building have been:

a. BIPV generation profile. This has been estimated from the BIPV modelling simulation results described in the section 4.5.2 and extrapolating these for larger BIPV capacities with a maximum of 600kWp, given by the total area of the building roof (8,000m^2) and system efficiency (90Wp/m^2, as projected 19.3kWp occupy 213.6m^2 due to mounting design). Expected annual energy yield is 1,330kWh/kWp.

b. Building electrical consumption profile. The global consumption of the building is measured by an electricity meter collecting data every fifteen minutes. The monitoring data from 2016 have been used to generate the annual consumption profile on hourly basis. The annual electricity consumption is 4,035MWh.

c. Economic conditions. Electricity provider in Demo#5-CRICURSA building is Endesa. The considered contract type is 6.1 with variable electricity tariff distributed in 6 different periods along the year, as shown in the following figure. Annual electricity bill reaches around 400,000€, as the sum of a fixed term of around 100,000€/year for power capacity (850kW) and counter leasing and a variable term depending on measured consumption and electricity tariffs collected in the following table. PV excess is remunerated. Although selling electricity tariff depends on pool market, but it has been estimated to be 5c€/kWh for the whole year in this study.

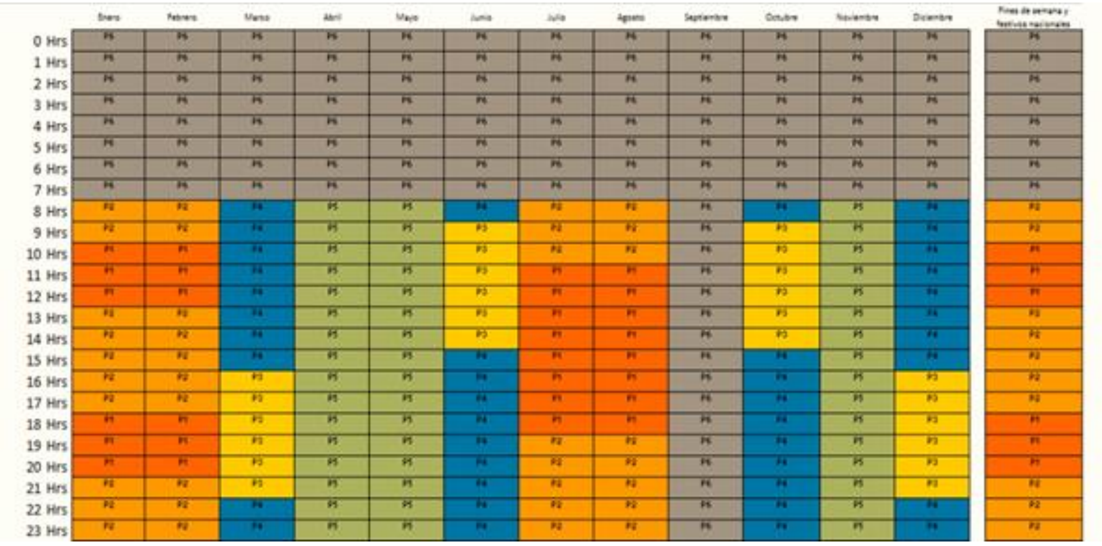


Figure 5.6 Distribution of electricity tariffs in 6 periods along the year in electricity contract type 6.X. Rows represent the 24 hours of a day and columns the 12 months plus an additional one for weekends and national bank holidays

Table 5.7 Electricity tariffs for DEMO#4 – CRICURSA building

Period	Price (€/kWh, tax 21% excluded)
P1	0.0976
P2	0.0927
P3	0.0854
P4	0.0811
P5	0.0627
P6	0.0596

d. BIPV generator cost. CIGS BIPV module shows an efficiency of 108W/m^2 and its price is projected to be 100€/m^2 by year 2021, according to PVSITES targets. Considering 50€/m^2 as the cost for conventional tiles, over cost due to the BIPV modules is supposed to be 50€/m^2. The rest of installation and commissioning costs are supposed to be 0,3€/Wp, resulting in a total over cost of 0.76€/Wp. In this case, taking into account the scale of the installation, a storage system cost of 400€/kWh has been considered.

5.5.2 Results

In the following table, main results from PVSITES planning tool are presented for different BIPV and storage capacities scenarios.

Table 5.8 PVSITES planning tool main results for DEMO#4 – CRICURSA building

BIPV capacity	Storage capacity	Self-consumption rate	Autarchy	CAPEX	Annual saving	Payback period
400kWp	-	89.1%	11.8%	304k€	39,696€	9
400kWp	100kWh	89.6%	11.8%	344k€	51,813€	7
400kWp	200kWh	89.8%	11.8%	384k€	55,539€	7
400kWp	300kWh	90%	11.9%	424k€	55,572€	8
500kWp	-	88.2%	14.5%	380k€	49,102€	9
500kWp	100kWh	88.9%	14.7%	420k€	61,927€	8
500kWp	200kWh	89.2%	14,7%	460k€	65,354€	7
500kWp	300kWh	89.5%	14.8%	500k€	65,413€	8
600kWp	-	87.1%	17.2%	456k€	58,154€	9
600kWp	100kWh	88%	17.4%	496k€	71,911€	8
600kWp	200kWh	88.5%	17.5%	536k€	75,065€	8
600kWp	300kWh	89%	17.6%	576k€	75,154€	8

5.5.3 Conclusions

BIPV generator payback period is 9 years for all the considered capacities (400kWp to 600kWp) mainly due to high self-consumption rate (from 87% to 89%) and energy yield (1,330kWh/kWp). Although profitability slightly decreases with the installed BIPV capacity, the potential saving will be also reduced, so actually the decision will depend on investment possibilities.

Although storage hardly rises self-consumption rate and related savings (<500€ in any case), it significantly increases profitability of the whole system thanks to the additional incomes from peak-shaving (from 11,856€ to 15,539€). Thus, the best configuration, in terms of profitability, is 400kWp of BIPV and 200kWh of storage capacity. Please notice that residual value of battery pack is considered in payback computation and its expected lifetime in this application is 15 years according to the simulation.

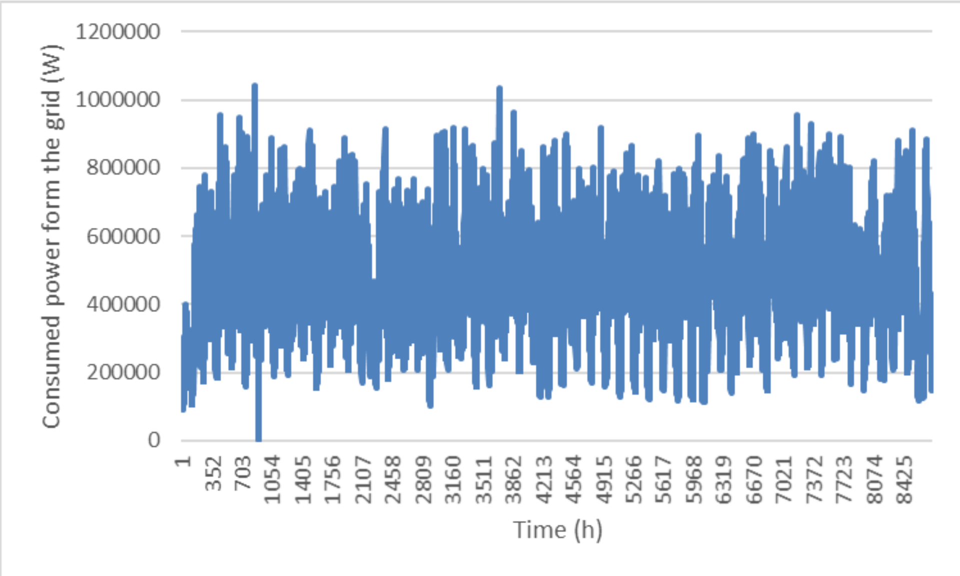


Figure 5.7 Yearly consumption on hourly basis for DEMO#4. Power peak overcomes 1MW

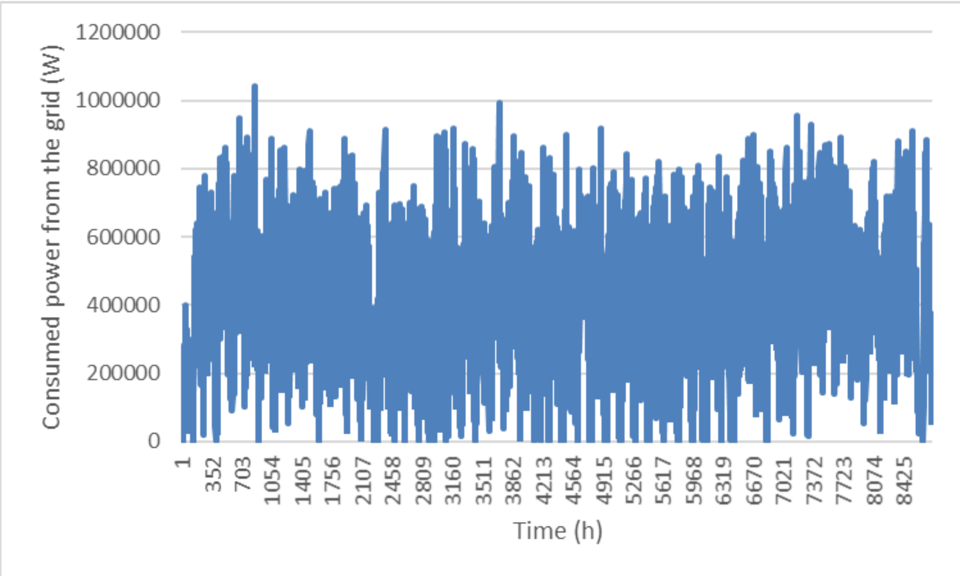


Figure 5.8 Consumption from the grid with BIPV generator of 400kWp and storage capacity of 200kWh with a conventional energy management strategy for DEMO#4. Power peak remains above 1MW and related costs above 100,000€

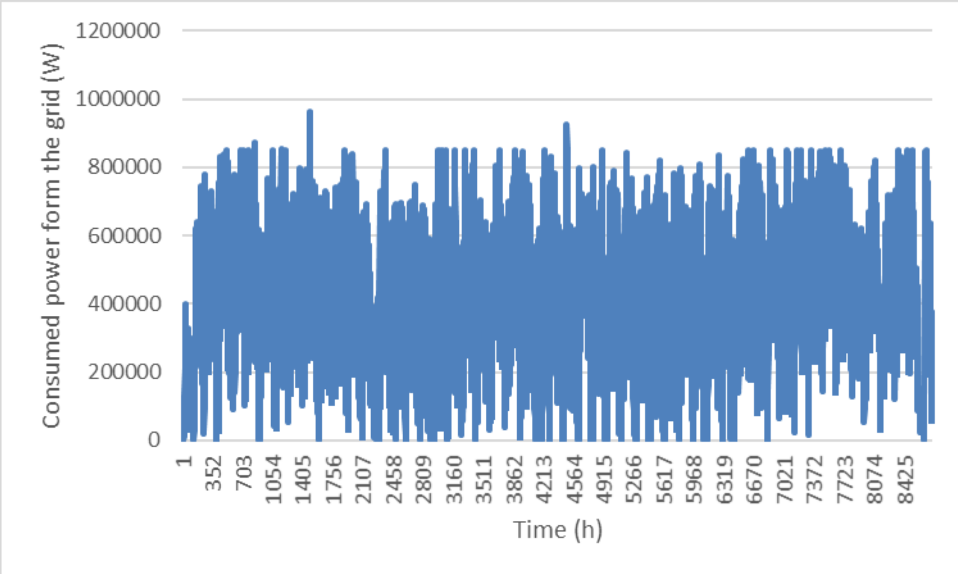


Figure 5.9 Consumption from the grid with BIPV generator of 400kWp and storage capacity of 200kWh with PVSITES predictive energy management strategy for DEMO#4. Power peaks are reduced to 850kW and related cost in 15,000€

5.6 DEMO#5 – Vilogia building, simulation PVSITES planning tool

5.6.1 Hypothesis

The initial assumptions for DEMO#5 – Vilogia building have been:

e. BIPV generation profile. This has been directly obtained from the BIPV modelling simulation results described in the section 4.6.2. Since BIPV generator capacity (17,000Wp) is given by the facade surface, other alternatives have been discarded. Expected annual energy yield is 13,819kWh.

f. Building electrical consumption profile. There are 4 electricity meters measuring the consumption of the common parts. The monitoring data from first quarter of 2020 have been used to generate the annual consumption profile on hourly basis. The annual electricity consumption is 16,447kWh.

g. Economic conditions. Electricity provider in Demo#5-VILOGIA building is EDF. The annual electricity bill reached 5,069€ in 2017, as the sum of a fixed term of 600 €/year and a variable term of 4,469€ due to a measured consumption of 31MWh. This means a purchase electric tariff of 12c€/kWh (+ 20% VAT).

h. BIPV generator cost. Crystalline silicon BIPV system shows an efficiency of 125W/m^2 and its price is projected to be 175€/m^2 by year 2021, according to PVSITES targets. Considering 75€/m^2 as the cost for conventional glazing material, over cost due to the BIPV modules is supposed to be 100€/m^2. PV storage inverter price is projected to be 1,600€ without the battery pack. The rest of installation and commissioning costs are supposed to be 0,3€/Wp, resulting in a total over cost of 1.3€/Wp.

5.6.2 Results

In the following table, main results from PVSITES planning tool are presented for different storage capacities scenarios.

Table 5.9 PVSITES planning tool main results for DEMO#5 – VILOGIA building

Storage capacity	Self-consumption rate	Autarchy	CAPEX	Annual saving	Power peak reduction
-	43.3%	36.4%	22,100€	718.4€	-
5kWh	52.4%	44%	24,600€	817.3€	30%
10kWh	59.3%	49.8%	27,100€	931.4€	50%
15kWh	65.4%	54.9%	29,600€	1032.8€	60%
20kWh	69.6%	58.5%	32,100€	1103.6€	65%

5.6.3 Conclusions

BIPV generator shows a payback period quite higher than 30 years for all the scenarios. The main reason of this underperformance is the low (1) energy yield (813kWh/kWp), (2) direct self-consumption rate (43.3%) and purchase electricity tariff (12c€/kWh). Storage increases self-consumption rate (up to almost 70% with 20kWh) and reduce required grid power capacity (65% for 20kWh) thanks to PVSITES predictive energy management strategy. However, this increases payback period mainly due to the difficulties to get additional revenues from it apart from increasing self-consumption rate. In fact, it is not possible to take great advantage from electricity tariff variability since it remains constant during daytime, peak-shaving is not remunerated and batteries must be replaced before 15 years.

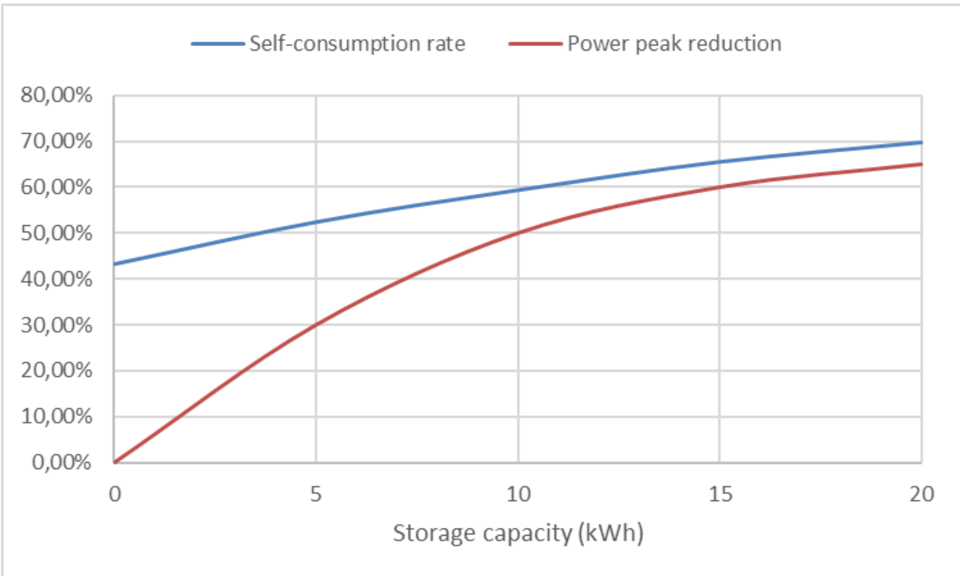


Figure 5.10 Estimated self-consumption rate and power peak reduction for DEMO#5 – VILOGIA building as a function of installed storage capacity

5.7 DEMO#6 – TECNALIA building, simulation by PVSITES planning tool

5.7.1 Hypothesis

The initial assumptions for DEMO#6 – TECNALIA have been:

e. BIPV generation profile. This has been directly obtained from the BIPV modelling simulation results described in the section 4.7.2. Since BIPV generator capacity (18,400Wp) is given by the available surface in South and South-East facades, other alternatives have been discarded. Expected annual energy yield is 15,494kWh.

f. Building electrical consumption profile. This building exhibits yearly global consumption higher than 2GWh with a baseline consumption of more than 150kWh. Since consumption is quite higher than expected BIPV generation, only consumption associated to the offices and laboratories behind the facades where the BIPV generator is going to be installed has been considered. This consumption has been estimated proportionally estimated to area of these facilities. Despite considering only this portion of the global consumption, the annual electricity consumption is higher than 200MWh.

g. Economic conditions. Analyzing historical electricity tariffs, it can be concluded that the average price of electricity is around 8c€/kWh.

h. BIPV generator cost. Crystalline silicon BIPV system shows an efficiency of 115W/m^2 in this building and its price is projected to be 175€/m^2 by year 2021, according to PVSITES targets. Considering 75€/m^2 as the cost for conventional glazing material, over cost due to the BIPV modules is supposed to be 100€/m^2. The rest of installation and commissioning costs are supposed to be 0,43€/Wp, resulting in a total over cost of 1.3€/Wp.

5.7.2 Results

In the following table, main results from PVSITES planning tool are presented. As there is no PV excess, neither storage capacity nor advanced EMS has been considered.

Table 5.10 PVSITES planning tool main results for DEMO#6 – TECNALIA

Storage capacity	Self-consumption rate	Autarchy	CAPEX	Annual saving	Payback period
-	100%	0.8%	23,920€	1239.5€	25 years

5.7.3 Conclusions

BIPV generator shows a payback period of 25 years if only incomes coming from electricity savings are considered. The main reason of this underperformance is the quite low (1) energy yield (<850kWh/kWp) due to meteorological conditions and vertical disposition of BIPV generator, and (2) purchase electricity tariff (8c€/kWh). Neither storage capacity nor advanced EMS makes sense in absence of PV excess.