

BIM – A driver for Energy Transition and BIPV Adoption

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Abstract

In the framework of an increasingly demanding legislation related to energy performance in buildings, the integration of photovoltaic systems in the building skin offers many possibilities and has a key role to play towards bioclimatic buildings. Therefore, practically, the most important technological challenges toward energy-efficient buildings are twofold: (i) bioclimatic design, considering eco-friendly sources as well as renewable and durable material, and (ii) Building Information Modelling methodology for the whole architecture, engineering and construction (AEC) process to support the simulation, visualization and management of a building's performance throughout its lifecycle. This paper addresses the ambition put on merging high performance computing, scientific models and methodologies for energy modeling, user friendly software tools and web based services, together with collaborative processes supporting sustainable design towards positive energy buildings, active skins and the emerging Building Integrated Photo Voltaic materials.

The EU-funded PVSITES project focuses on these needs with the development of BIM-based software for the simulation of BIPV products and forecasting their impact on building energy performance. This project aims at contributing to the uptake of both BIPV implementation and its integration within a holistic BIM process.

Keywords: Building-integrated photovoltaics, BIPV, software, design, calculation, BIM

1. Introduction

Reducing energy consumption and carbon footprint of buildings has become a worldwide crucial issue in the construction sector, leading to increase energy performance requirements and to incorporate innovative green building concepts in architectural design towards Nearly Zero Energy Building (NZEB) [1]. To achieve this, bioclimatic design must be investigated to evaluate the potential of natural resources at the very early stage of the AEC process (Architecture/Engineering/Construction) and renewable energies incorporated as valuable assets within the building programmes.

Recently, Building Integrated Photovoltaics (BIPV) is promised to a bright future for commercial and residential buildings because of the limited Building-Added PV (BAPV) roofing possibilities. Integration into the building skins (e.g. facades) of these novel products and calculation of their performance against electrical, thermal and daylighting objectives are the major challenges for architects and engineers. Therefore, the assessment of solar energy potential at the conceptual stage of the BIM-based AEC process coupled with a dynamic simulation and planning program for the design and optimization of photovoltaic systems would undoubtedly support and facilitate BIPV (and also BAPV) deployment for both new and renovation buildings projects.

The simulation and planning software are relevant in designing green buildings because they provide projected qualitative and quantitative results of the building's performance. They can be used either to help making decisions (comparison of the advantages versus impacts of several technical scenarios), or to justify the choices based on relevant key indicators, at the end of the design process.

There is however a condition to optimize the green building design workflow: the extended AEC team must "begin with the end in mind" by collaborating from the very early conceptual stage towards the validation of the final product through successive design analysis and verification. Indeed, exchange between design team members (architects, engineers, energy consultants) might be complex and time consuming. BIM is a sum of processes and technologies that enables an integrated design and was consequently developed to facilitate exchange amongst the

design team. The BIM model encompasses building geometry, spatial relationships, geographic information, and quantities and properties of building components.

In the context of energy-efficient and NZEB buildings, the EU-funded PVSITES project develops new generation digital solutions to be proposed within a Software as a Service (SaaS) strategy: linked to the main design and BIM software, it aims at being used by most of the designers and bridge the gap with manufacturers. Using interoperable formats and web based digital twins of BIPV products, securing and fostering data exchange within collaborative workflows, the solution intends to support NZEB building designers, from early decisional stages to pre-design,

2. A building information management (BIM) framework for sustainability design

2.1 Holistic BIM: object-oriented modelling with the end in mind

Historically, CAD software represented 2D geometry based on wireframe graphical elements. More complex information, such as the relationships between graphical elements, could not be added. The next generation of CAD, initially focused on 3D modeling for creating complex geometry in order to support their visualization, and thus enabling realistic rendering and light effects. More recently, object-oriented CAD systems replaced graphical symbols with building primitives or objects, capable of representing the characteristics of physical objects like mechanical components or building elements. These building elements can be parametrically calculated and displayed in multiple views, and non-graphic attributes can be assigned to them, thus enabling such elements or objects to become smart (parametric, contextual). This combination of parametric 3D geometry with assigned rules and dimensions represents therefore the “single source of truth” and allows the representation of complex geometric and functional relationships between building elements. BIM was initially conceived as the latest generation of object-oriented CAD systems, in which all of the intelligent building objects that constitute the design of a structure can co-exist in a single virtual structure that captures everything known about the structure.

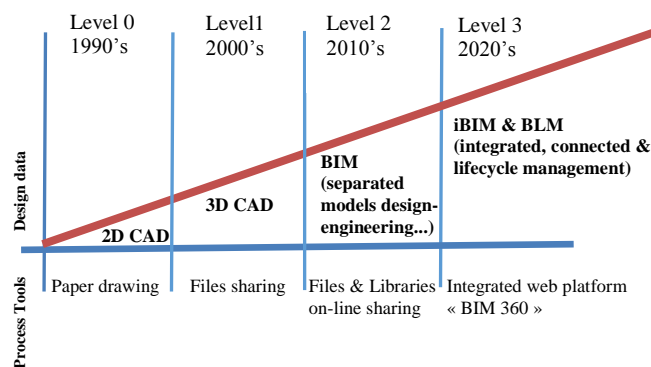


Fig. 1: BIM evolution

BIM success is all about a holistic approach towards understanding the whole AEC building process and streamlining the data- and workflow through the entire project lifespan in order to achieve efficient and quality projects that match with energy transition targets. Using BIM will allow to integrate and achieve holistic objectives about energy and environmental issues in building projects: BIM can drive towards life cycle operation information and data maintainability via communicating the future-proofing strategy from a whole life perspective and ensuring knowledge transfer across all stages. BIM models can be further used to support both Building Operations and Facilities Management through BIM workflows extension and Digital Twins on the web, anticipating platforms of O&M services and information exchange regarding all aspects of building operational performance.

2.2 Integrated and connected BIM towards digital twin for building performance simulations

The major challenge of this forward-looking digital planning method is to provide comprehensive building performance analyses at the early stage of the building design process while implementing different computational technologies that exist across multiple domains into the conceptual BIM model. For instance, to perform solar building design, architects need to consider different technologies (e.g., building-integrated photovoltaic, solar

thermal, and daylighting) into a combination of software and effectively simulate the impacts of the diverse natural resources to provide building performance analysis during the design phase. However, traditionally, architects and engineers have found it difficult to effectively perform building performance analysis mainly due to the following factors:

- Professional processes still based on 2D CAD drawings, rarely 3D/BIM driven;
- Current analysis software requires specific data that has to be derived from the CAD model or a discrete input model or must be created to fit each kind of simulation and calculation;
- Building design and technical studies are conducted separately, rarely in collaborative holistic approach;
- BIM adoption is low, due to the cost of equipment, software and lack of resources and time for training;

Seamless integration among the tools and between design models and building energy analysis models will be proposed based on an advanced BIM-based platform. This integrated approach towards sustainable design is expected to efficiently provide energy performance analyses based upon multiple simulations at the early design phase and readjusted throughout the whole lifespan of the building based on real-world captured data.

Integrated BIM with a consistent and structured data management is the key to generate such a digital twin model whose dynamic performance can be studied by building simulation tools for a variety of different boundary conditions (figure 2).

However, such an integrated building performance analysis would require a global and advanced calculation method based on multi-domain simulations. This method will enable the completion of a building performance analysis with a unified BIM model (figure 3) which can provide detailed physical and functional characteristics of buildings. In addition, it can be integrated with various environmental modeling and simulation approaches in order to achieve a holistic design and assessment of low carbon and energy-efficient buildings.

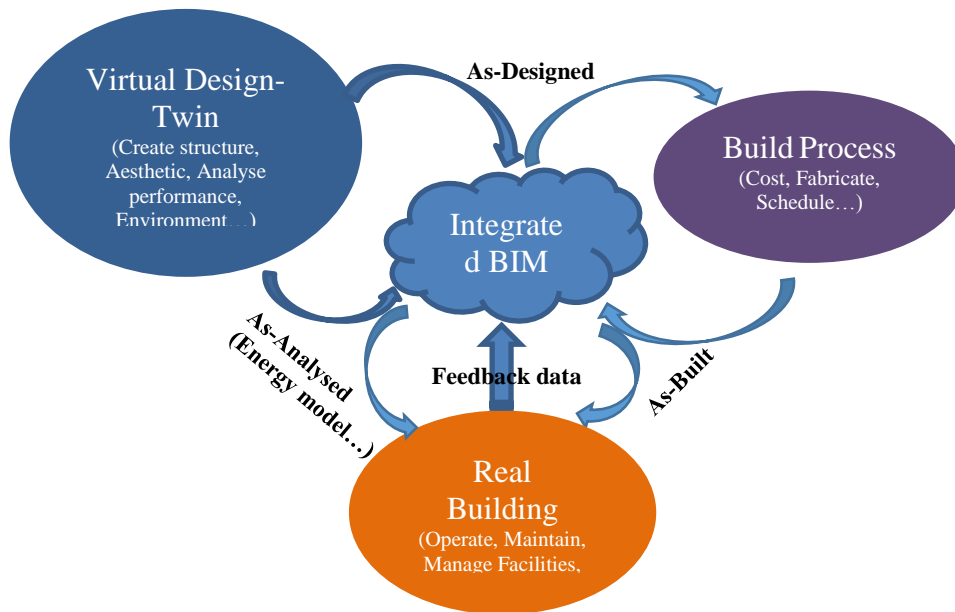


Figure 2: Integrated and connected BIM encompassing the three phases to allow enriched data and greater knowledge

In the framework of the PVSITES project, a ray tracing algorithm has been developed to model solar radiation interaction with complex urban environments and its effects, including the total irradiance at pixel level in the 3D scene then the hourly to yearly photovoltaic production at module level. Lighting control integrated with daylighting is recognized as an important and useful strategy in terms of energy-efficient building design. It is believed that proper daylighting schemes can help reduce the energy demand and contribute to achieving environmentally sustainable building developments. Therefore, passive solar heating and lighting are important issues to be taken into consideration towards the reduction of energy consumption in new buildings and the design solar PV panels. This can be achieved at the very beginning of the conceptual design by advanced simulation methods and techniques allowing appropriate building design (bioclimatic architecture) and energy efficient systems and technologies, such as solar systems. BIM-based simulation tools allow for input of a single BIM model data to create energy models, this process can seamlessly insure the data workflow from design to analysis thus eliminating redundant operations such as re-entering the building's geometric information from the design model.

3. BIM-based methodology for BIPV

This section presents the BIPV simulation features available in PVSITES.

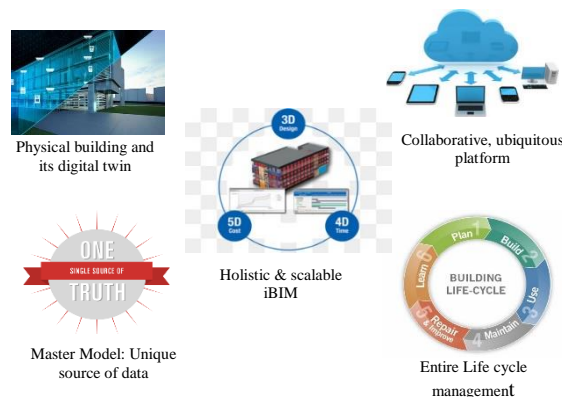


Figure 3: iBIM main features

The ambition is to provide the building project teams - and architects at first level - with a fast, reliable and easy to use digital solution, BIM-ready and connected to the master project virtual workspace (e.g. BIM - CAD solution).

3.1 Global workflow

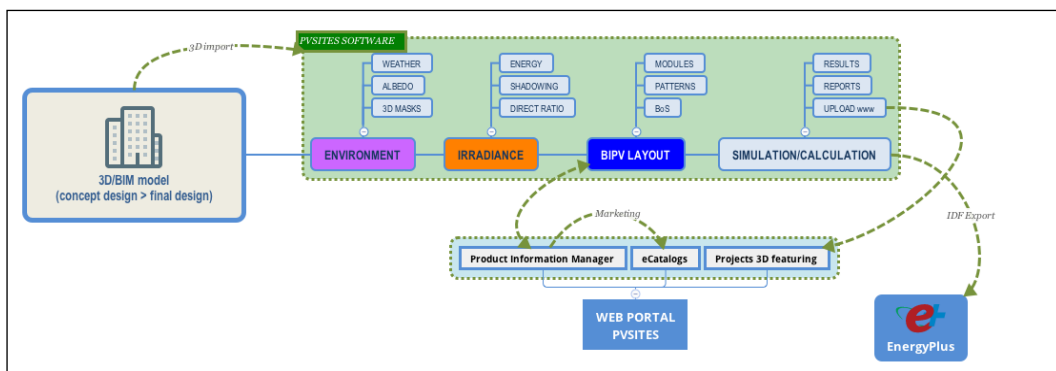


Figure 4: Global workflow for BIPV simulation

The PVSITES BIM solution, under development, is based on the BIMsolar® software [2], as a combination of two innovations:

- A standalone “BIMsolar®” software for high performance computing in solar simulation and calculation over imported 3D models, BIM-ready and user friendly;
- A connected web portal aimed at exchanging data (products features) and projects with standalone software, enabling manufacturers to disseminate innovations towards designers from element to building

level, in a “web to 3D” design workflow. In return, designers can showcase their BIPV projects on the web portal.

The development followed AGILE methodologies and was as such continuously inspired by “user stories” from BIPV experts, architects, manufacturers and installers.

STEP #1: Importing a BIM model into a solar environment

Importing a simple 3D model or a BIM model to simulate its solar and BIPV performance is made through a “classic” import (in other words, the “File>Open” function). Native BIM and software formats can be imported. A specific plugin is being developed for the Autodesk® REVIT® BIM solution.

The PVSITES algorithms then read the 3D geometry in its native format and reconstruct a model into the PVSITES workspace. The user gets a 3D digital twin model able to perform solar simulation and BIPV systems calculation.

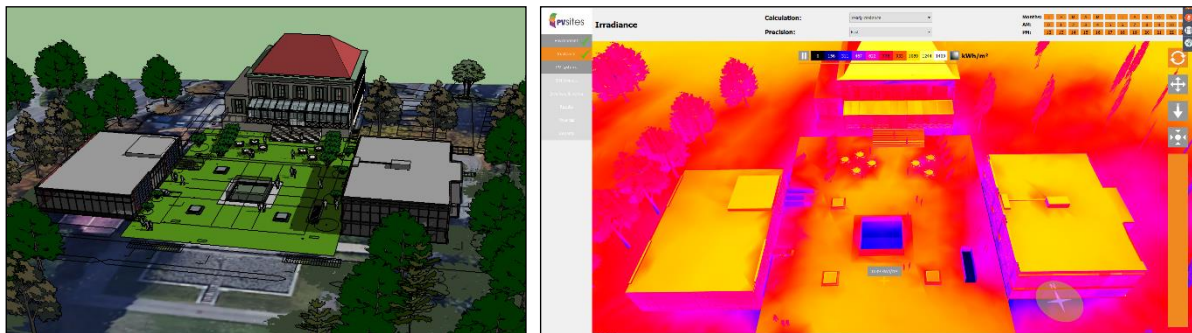


Figure 5: Twin models between architectural 3D model and PVSITES © BEAR-iD Architecture

Once the import is done, the main virtual workspace becomes the PVSITES twin model. No update can be made if geometric changes occur; in this case the user has to import the updated model as a new project.

During the import process the geometry of the model is detected and the set of polygon mesh that forms the architectural envelope (walls, floors, roofs, windows), and the spatial relations between them, are analysed. This enables to import a model from almost any CAD and BIM format. To perform the import, some information such as textures and native BIM families of objects in Revit is recognized.

The surrounding environment (buildings, vegetation, even terrain modelling) has a considerable impact on a building solar performance because of shadings/masks effects on irradiance. It is thus essential to import it properly within the architectural project, albeit with the lowest possible level of details to prevent supernumerary mesh generation, in order not to exceed computer capacity.

The PVSITES solution is compatible with the leading 3D and BIM software, as shown in Table 1. Thus it can be used for almost any project.

Tab. 1: CAD and BIM compatibility with PVSITES

| Supported formats for 3D import | |
|---------------------------------|--------|
| Open BIM (ISO) | .ifc |
| GreenBuilding XML | .xml |
| EnergyPlus™ format | .idf |
| Trimble® SketchUp® | .skp |
| AutoDesk® REVIT® | plugin |

STEP #2: Environmental conditions

Once a 3D model is imported into PVSITES, solar conditions must be set up for the whole project (building and environment) as they are crucial inputs for the BIPV performance. Parameters that can be set are:

- Geographic location and weather data import: a Google Maps popup window opens to select a weather

data station; alternatively direct import of a weather file is possible (supported files formats: .epw and .tmy2).

- Albedo (e.g. irradiance reflectivity) for the surfaces within the 3D virtual workspace: mouse selection allows to set values for ground, walls, roofs and surroundings. Realistic values are to be chosen by the user; the contextual assistant proposes typical values from the literature.

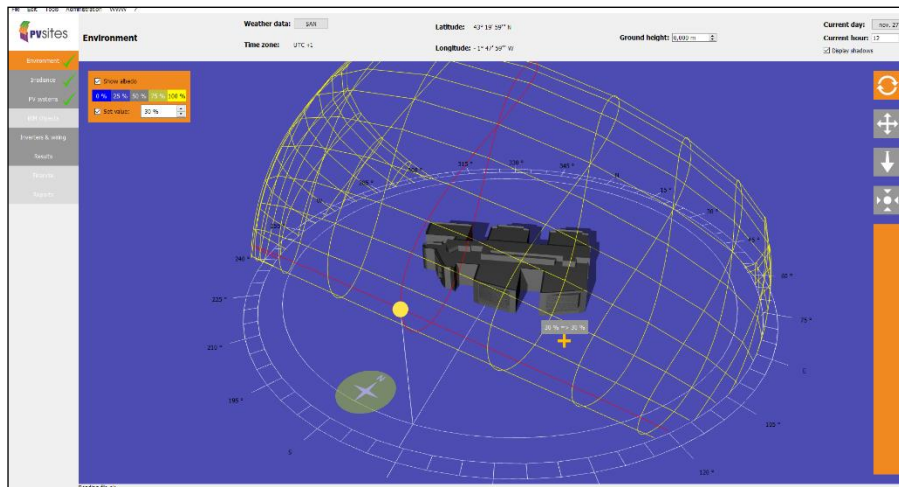


Figure 6: geo-location, weather data and albedo settings

The weather files (minute to hourly step values) feed the irradiance simulation algorithms with direct and diffuse irradiance values: Diffuse Horizontal Irradiance (DHI) and Direct Normal Irradiance (DNI). Weather data also provide dry bulb temperature used for module temperature calculation.

STEP #3: Irradiance simulation

Tilted surfaces, such as BIPV glass walls and atriums, require high performance computing and accurate models to discretize the incoming solar energy at module or even cell level.

Irradiance value for each pixel of the 3D scene is calculated using EnerBIM's raytracing simulation core, also used in other software [3], at each step of the defined time range (based on the time resolution of the weather data).

Monte Carlo ray tracing is used to compute accurately the complex phenomenon of irradiance, taking into account direct and diffuse energy, as well as multiple reflections on the environment [5, 6].



Figure 7: Raytracing principle – Irradiance rendering (sources: ©Wikipedia - ©ENERBIM)

Irradiance display uses a view-dependant progressive refinement approach: irradiance is computed at key points on the image and stored in the 3D model. Zooming or changing point of view will re-use some of the key points already computed and will trigger the calculation of new points.

This results in a very fluid rendering of irradiance. After a couple of camera movements around the scene, delta calculations are few enough so that the user can navigate real time in his irradiance lit scene.

Users can alternatively select the “balance” and “accurate” calculation modes to get higher resolution in irradiance simulation, at the cost of a longer computation time.

Indicators are derived from the irradiance simulation:

- The direct irradiance ratio indicates the proportion of Direct Irradiance received in the plane of each pixel on the 3D scene (pixel is the smallest unit to display in this “compute for is seen” strategy).
- The shadowing ratio indicates the proportion of total irradiance (direct, diffuse and reflected) received on each pixel of the scene.

STEP #4: BIPV layouts – Balance of System

PVSITES BIPV products are diverse and different in complexity. To meet architectural integration requirements, as well as electrical, optical and thermal performance, a BIPV Product Information Manager (PIM) has been elaborated. The PIM aims at configuring virtual BIM objects with:

- Geometrical data: cell configurator, module configurator, pattern of cells configurator, module spacing, strings arrangement and inverter localization to generate 3D pathways for strings into the 3D model.
- Electrical data: I, V, Power values, diodes, busses.
- Thermal data: Nominal Operating Cell Temperature (NOCT), power losses coefficients, thermal conductivity, thermal transmittance, thermal emissivity.
- Optical data: solar and visible transmittance, solar and visible reflectance, colour.
- Layout features: horizontal/vertical cells and modules arrangement, mounting and fixing devices, framing.

The PIM works online as a web service, bridging manufacturers and users’ databases of products with the virtual workspace for contextual issues. Once generated, the virtual PVSITES BIM objects (e.g. parametric dynamic components integrated into the BIM tools [7]) are dragged and dropped into the PVSITES workspace and applied in 3D onto the building surfaces. Becoming true BIPV components, they provide their embedded technical characteristics data to the simulation and calculation models (geometrical, electrical, thermal, optical).

The user drives a “What if Analysis” to fix some values, step-by-step, experiencing provisional results. Decision support is provided form real time contextual indicators such as peak power (kWp), BIPV surfaces, number of modules, shadowing effects, primary production or array yield (kWh/kWp).

Example: The spacing and vertical/horizontal organization for PV cells integrated in a glass wall must fit with the existing structure. The PVSITES simulation tool enables user to handle the objects then calculates the PV production considering transparency and the thermal impact on the overall energy balance of the building.

Once fixed, the PVSITES objects should be transformed into specific BIM objects for the main BIM workspace, e.g. the CAD solution; this feature is under development for AutoDesk® REVIT® families of BIPV objects.

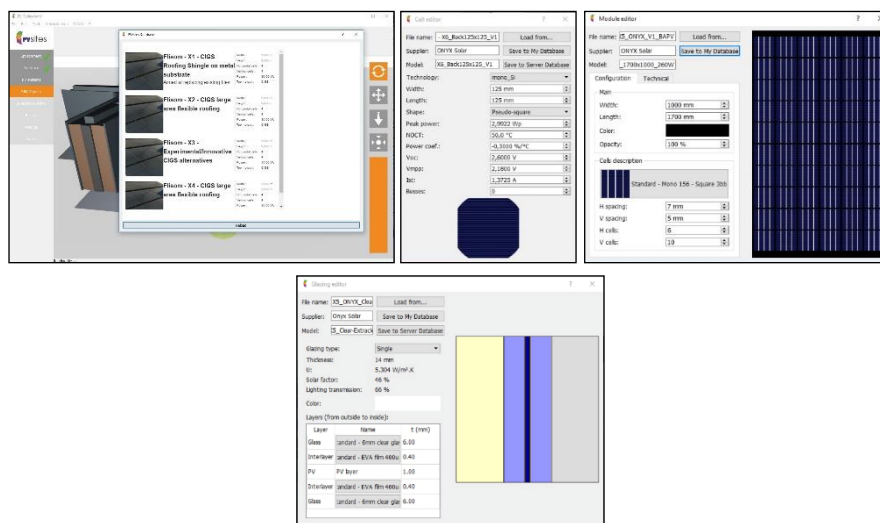


Figure 8: Product Information Manager; from cell editor to glazing editor

STEP #5: BIPV calculation and outcomes

BIPV calculation is achieved through physical and system models based on the BIMsolar[®] software.

PVSITES objects feed those models with configured inputs from the PIM. The electrical, optical and thermal models have been developed for overall BIPV configurations and for tilted or curved (convex) surfaces:

- Electrical generation for various PV technologies: Crystalline-Si, CIGS, CdTe, Amorphous-Si, based on adapted models including diodes and resistors.
- Electrical selection for inverters, MPP trackers and strings regarding wiring, power and I/V specifications.
- Optical transmittance, reflectance for normal incidence reduced model,
- Thermal conductivity, thermal emissivity, resultant solar factor for cell and module level thermal calculation and impact on the energy balance at building level.

Energy balance at building level and impact on thermal comfort

EnergyPlus[™] models have been chosen to provide general calculations on a building’s energy balance.

The PVSITES software imports any *idf* file from the user and enriches it with thermal inputs related to BIPV systems: PV surfaces with their description and thermal data.

Thermal experts and energy consultants should be able to quantify the impact of BIPV adoption within their engineering process using coupled PVSITES and EnergyPlus[™] software.

If no *idf* file is available, the PVSITES software will be able to generate it from its 3D geometry and BIPV features.

Outcomes

The following table summarizes the diverse outcomes provided through BIPV calculation:

Table 2: Outcomes from the PVSITES BIPV and EnergyPlus[™] building energy calculations

| | Electrical | Thermal | Energetics | Daylighting |
|-----------------|-------------------|----------------|-------------------|--------------------|
| Outcomes | Production kWh | Module temp. | Irradiance (3D) | Light transmission |
| | Array yield | U values | Heating needs | Daylight factor |
| | Losses | Solar factor | Cooling needs | |
| | Perform. Ratio | Givoni comfort | | |

4. Results

Efforts have been made these recent years to unite BIM and energy in order to bridge the gap between energy modeling and architectural design. Main outcomes are already delivered to professionals:

- 3D modeling can generate energy modeling, for bioclimatic (passive) performance leading to positive energy modeling: geometry is interpreted via ray tracing technology; solar energy (irradiance) is distributed via probabilistic methodologies (Monte-Carlo [5, 6]).
- Models can be embedded into various forms of software; standalone software are able to exchange data with web-based platforms.
- Digital twins become operational, even for scientific purposes: products are virtualized, configurations are made versatile in contextual mode – element level adapted to building level and vice versa -; BIM objects are now replacing traditional tables of parameters.

BIPV designers using the PVSITES software can visualize and interact with the energy performance of their building. The software provides results through 3D graphical user interfaces, diagrams, and histograms. These results are updated in real-time after each data configuration modification or BIM object reconfiguration with the PIM (updated online and attached to the user).

Amongst the relevant produced indicators, we can list:

- PV production figures and histograms (from array yield to Performance Ratio).
- The impact on energy needs of the building. Two indicators are affected by BIPV systems: Heating and Cooling demands.
- The impact on thermal occupant comfort (Givoni Comfort Zones [8]).

When more accurate results are needed, such as thermal calculation and comfort evaluation in each room, the Dynamic Thermal Simulation (EnergyPlus™) can be used. The EnergyPlus™ open source software is available for free download and “incorporated” in several design solutions.

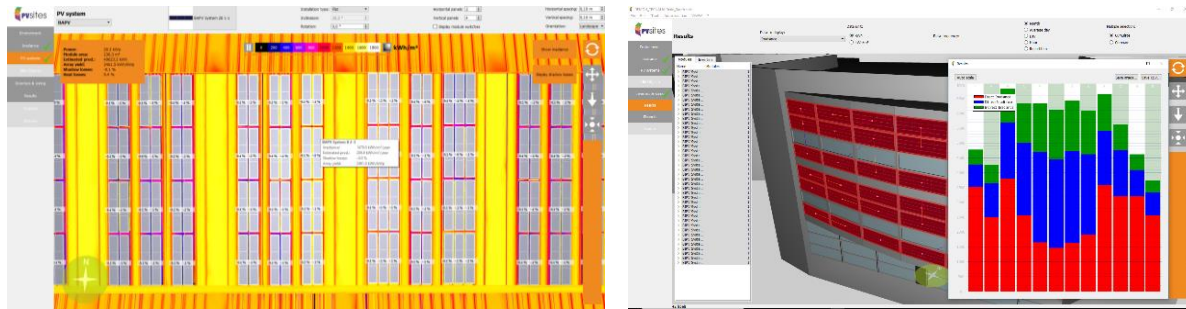


Figure 10: Results displayed to user in diverse graphical modes

5. Conclusion

BIPV performance can be simulated, calculated and visualized using the BIM-based software developed within the PVSITES project. Indeed, many decision-making criteria are available to help building designers optimize the electrical production (PV) but also the induced thermal comfort of the designed BIPV implementation, while minimizing the building energy needs, to achieve NZEB targets.

To optimize the design workflow, the PVSITES solution allows instant import of 3D models combined with intuitive and real-time results display. Strengths reside in that designers can easily evaluate the impact of any change of BIPV product configuration, or design option, in collaboration with manufacturers and end-users, as part of their normal workflow. Consequently, this solution helps minimizing the design risk. It allows to save time and money while optimizing bioclimatic characteristics and/or positive energy performance, for both new projects and the retrofit of the existing building stock.

The ability of this software to be used on existing buildings for refurbishment strategies with lower cost BIPV products offers strong opportunities, from evaluation to decision support, and considering energy savings coupled to improvements to thermal comfort, aesthetics and to the conjunction of performance and ecology.

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