



Guidelines on building integration of photovoltaic in the Mediterranean area



FOSTERinMED

Fostering Solar Technology in the Mediterranean Area



Project
funded by the
EUROPEAN UNION



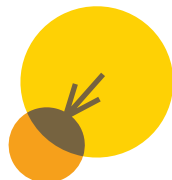
**ENPI
CBCMED**
CROSS-BORDER COOPERATION
IN THE MEDITERRANEAN



Project
funded by the
EUROPEAN UNION



This publication has been produced thanks to the financial support of the European Union
under the ENPI CBC Mediterranean Sea Basin Programme



FOSTEr in MED

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The total budget of FOSTER in MED project is 4,5 million Euro and it is financed for an amount of 4,05 million Euro by European union through the ENPI CBC Mediterranean Sea Basin Programme (www.enpicbcmmed.eu).

Statement about the Programme

The 2007-2013 ENPI CBC Mediterranean Sea Basin Programme is a multi-lateral Cross-Border Cooperation initiative funded by the European Neighborhood and Partnership Instrument (ENPI). The Programme objective is to promote the sustainable and harmonious cooperation process at the Mediterranean Basin level by dealing with the common challenges and enhancing its endogenous potential. It finances cooperation projects as a contribution to the economic, social, environmental and cultural development of the Mediterranean region. The following 14 countries participate in the Programme: Cyprus, Egypt, France, Greece, Israel, Italy, Jordan, Lebanon, Malta, Palestine, Portugal, Spain, Syria (participation currently suspended), Tunisia. The Joint Managing Authority (JMA) is the Autonomous Region of Sardinia (Italy). Official Programme languages are Arabic, English and French (www.enpicbcmmed.eu).

General statement on the European Union

European Union is made up of 28 Member States who have decided to gradually link together their know-how, resources and destinies. Together, during a period of enlargement of 50 years, they have built a zone of stability, democracy and sustainable development whilst maintaining cultural diversity, tolerance and individual freedoms. The European Union is committed to sharing its achievements and its values with countries and peoples beyond its borders.



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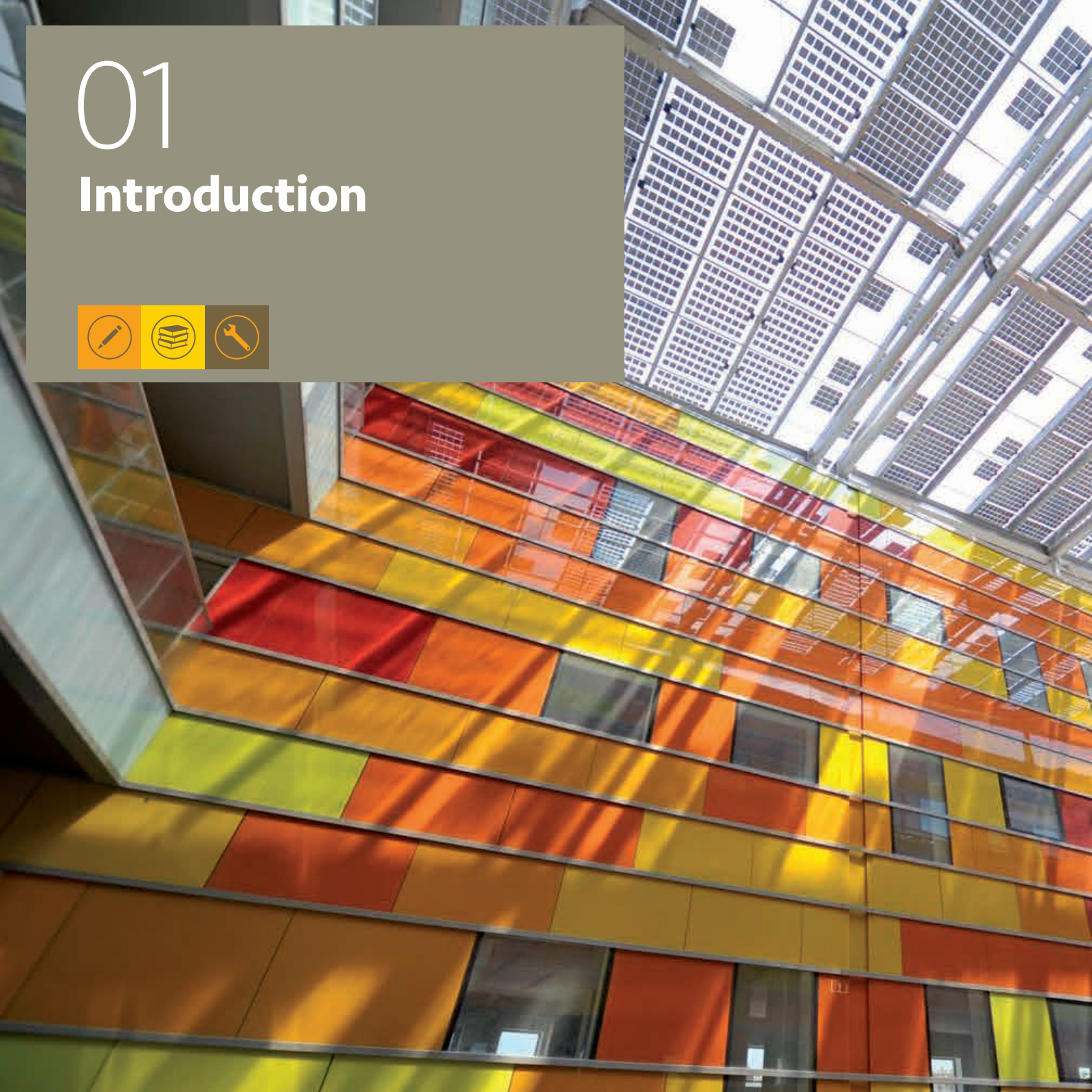
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01

Introduction





What is Building integrated Photovoltaic (BIPV)?

Photovoltaic is a widespread technology that allows the generation of direct current (DC) power through sun irradiation. PV systems are composed by PV cells of a semi-conductor material, joined together to form a PV module or panel, that can be used standing alone or on buildings. There's two ways to fit PV on new or existing buildings: integrating it, or simply installing it. In this last case we would talk of BAPV (building-applied photovoltaic), while BIPV refers to PV modules that are planned by a designer in order to substitute (not cover) a common building element. This can be a roof, a façade cladding, a shading element, a parapet. Thanks to the many variety currently offered on the market, the designer can decide not just the cell power and typology, but also its size, color and transparency.

Why use solar power on buildings?

The key concept that hides behind the definition of BIPV is that photovoltaic can have also more architectural functions in the buildings than the only energy production. Waterproofing and shading are only few examples of them. That is the best way to make it as profitable as possible from an economic and environmental point of view. If PV systems are installed on buildings no other land use is required and the electricity is directly generated at the point of usage. This will reduce the distribution and transmission losses of public electricity networks.

If PV systems are correctly taken into account and integrated in the design phase, the opportunities for designers will be even more appreciable. The PV can be completely seen as a building material offering multiple technical and aesthetic possibilities and contributing to create energy conscious and comfortable environments.

Nature of the Guidelines

These guidelines have a key role in the FOSTERinMED project. They aim at disseminating and diffusing knowledge in the partner regions and other areas. They are thought as a simple tool useful to approach BIPV and get the basic needed information in order to plan, design and install PV systems.

Implementation and dissemination

The guidelines main goal is to provide educational material for the FosterinMED training paths. They are addressed to university students, architectural and plant designers as well as installers, who will have a basic reference tool to understand the technology and the best way to integrate it in buildings.

These guidelines are also expected to be a benchmark to help designers in determining BIPV viability, but also local planning authorities in recommending best practices. The guidelines are to be widely distributed within the PV industry, building construction groups, design professionals, building financiers and planning authorities and can be made available to other organizations; in a few words, it is addressed to all the stakeholders of the PV value chain.

The main stakeholders are:

- University students
- Architectural and plant designers (Architects, Engineers, ...)
- Installers

But they can be of interest also for:

- National public authorities
- Local planning authorities
- Power utilities
- Network service providers
- Financing organizations
- Building owners
- Building constructors

Structure of the guidelines

The guidelines are structured to allow different stakeholders to identify information that is relevant to them. A simple set of icons will guide the readers to the part of their interest.

The first part is aimed at defining the current PV technologies that can be applied to buildings. The second part shows the added value of BIPV in terms of innovative design, energy efficiency and cost.



**ARCHITECTURAL
AND PLANT DESIGNERS**



UNIVERSITY STUDENTS



INSTALLERS

The third part deals with the performance of integrated systems, their sizing and requirements. The fourth part shows some best practices in the Mediterranean area.

The annexes, presented in form of DVD at the end of this publication, offer an overview on the electrical power generation and distribution in the partner regions, highlighting critical aspects and possible solution offered by the implementation of BIPV.

02

Pv Module Types





There are different types of photovoltaic modules, but the most commonly used for building integration are crystalline (mono- and poly-) and thin film modules. To these are to be added some new prototypes as hybrid, concentration and luminescence PV.

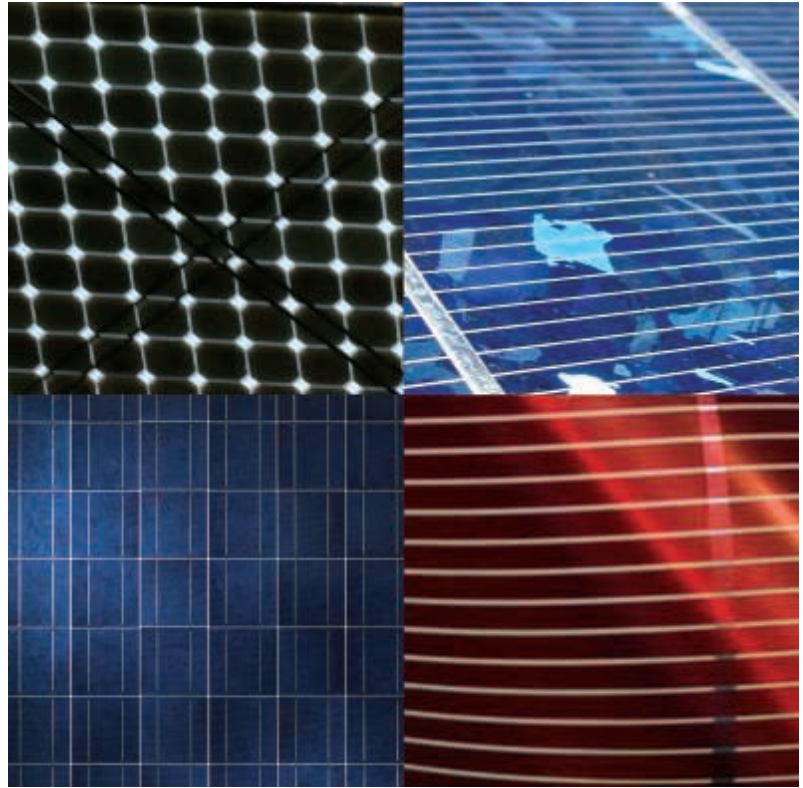


Fig 1 Different PV panel types

Crystalline modules are based on silicon cells and have a high efficiency. They are, however, more expensive than thin film modules. Made from a large crystal of silicon, monocrystalline solar panels typically comprise highly ordered blue-black polygons. Because they are the most efficient type of PV module in good light, with a standard condition efficiency typically in the range between 15 and 20%, they are often used in applications where installation square footage is limited, giving the end

user the maximum electrical output for the installation area available. Their embodied energy -the energy required to produce them- is greater than other PV types.

Characterized by its shattered glass look because of the manufacturing process of using multiple silicon crystals, **polycrystalline solar panels** are the most commonly seen solar panels. They are a little less efficient than mono-crystalline panels, having a more disordered atomic structure. Their energy efficiency is generally at 14-17%. Life expectancy is around 20-25 years. Thin film modules contain an ultra-thin amorphous photosensitive layer of silicon or alternative materials such as copper indium diselenide (CIS) or cadmium telluride (CdTe) deposited onto a low-cost backing, such as glass, plastic or stainless steel. Amorphous silicon solar panels are common for building integrated photovoltaic (BIPV) applications because of their many application options and aesthetics.

Thin films can be rigid or flexible, and can be produced in various colours, giving great versatility for different applications and sites. They require relatively low amounts of raw material to manufacture, are suited to automated production, and for this reason are relatively cheap to make.



Fig 2 Thin film PV mounted on roof

However, efficiencies are lower (e.g. 4-8%), as is life expectancy (15-20 years). Non-silicon-based thin-film modules, such as those using CdTe and CIS, have better efficiencies, with some exceeding 10%. They are however affected by a decrease of efficiency during the first operating year.

Peel-and-stick thin-film solar cells combine specifically formulated ceramics with thin films. A Meso-Super-structured Solar Cell (MSSC) can be printed directly onto glass and processed at below 150° C to produce a semi-transparent, robust layer. The new panels offer great potential for architects, façade engineers and builders. They can be produced from inexpensive, abundant, non-toxic and non-corrosive materials and be scaled to any volume. They can be printed directly onto glass in a range of colours, making them ideal for glazing panels and façades.

An ultra-thin amorphous silicon PV layer can be used to cover mono-crystalline PV cells. The advantage of these cell types is that they are more sensitive to solar radiation and perform better at high temperatures than conventional crystalline silicon PV cells. However, these cells come at a cost premium. They are commonly known as multi-layer cells.

Hybrid photovoltaic PV-T modules combine photovoltaic cells with a



Fig 3a, 3b Hybrid thermal PV panel and element

solar thermal collector, which captures the remaining energy and removes waste heat from the PV cells. Such systems can be engineered to carry heat away from the PV cells thereby cooling them and thus improving their efficiency.

Concentrated photovoltaic systems (CPVs) replace solar cell plates with a panel of optics that concentrate sunlight onto a set of small, high-performance solar cells, where light is converted into electricity. The light concentration allows higher efficiency for the cells' PV conversion and permits to replace large part of photoactive materials with cheaper components concentrating the light.

The reliability of the CPV systems has not yet been proofed in field for long time as for standard PV, since this technology has achieved an industrial dimension only in the last years.

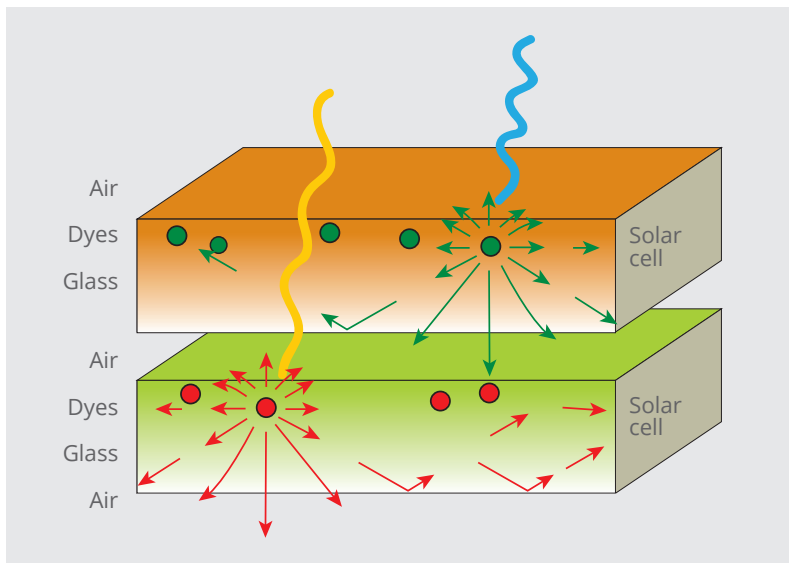


Fig 4 Scheme of a luminescent solar concentrator

They can reach high efficiencies but only if two track axis concentrators are used.

The luminescent solar concentrator LSC is a simple device at its heart,

employing a polymeric or glass waveguide and luminescent molecules to generate electricity from sunlight when attached to a photovoltaic cell. The principle used is to disperse on a Plexiglas plate type fluorescent dyes that absorb part of the solar light and then emit it within the same slab. The radiation is conducted towards small solar cells arranged along the edges that transform it into electricity. Despite its potential for generating low-cost solar power (they are more efficient than traditional models, as they also produce with little sun, do not need a particular inclination and can be also placed vertically, which makes it ideal for BIPV), LSC development faces numerous challenges, the majority of which are related to the luminescent materials used in their design. The research is still ongoing and the product is still not available on the market.

2.1 Colour

The colour of photovoltaic cells is a result of their particular manufacturing process, and thus simply a result of the treatment given to the silicon they are made of. Certainly, the colour of photovoltaic cells affects the absorption of solar radiation, meaning that the generated energy will vary according to the colour used. Different colour PV gives the chance to be integrated as an artistic coloured PV skylight, curtain wall, balcony or any other multifunctional constructive solution and thus solving the problem of the use of PV in those cases where integration is mandatory, as in most of the European historical town centres.

2.2 Material

PV cells are made of semiconductor materials. The major types of materials are crystalline and thin films, which vary from each other in terms of light absorption efficiency, energy conversion efficiency, manufacturing technology and cost of production.

2.2.1 Mono-crystalline silicon

Mono-crystalline silicon cells are the most common in the PV industry. The main production technique is the Czochralski (CZ) method. High-purity poly-crystalline is melted in a quartz crucible. A mono-cry-

stalline silicon seed is dipped into this molten mass of polycrystalline. As the seed is pulled slowly from the melt, a mono-crystalline ingot is formed. The ingots are then sawed into thin wafers about 200-400 micrometers thick (1 micrometer = 1/1,000,000 meter). The thin wafers are then polished, doped, coated, interconnected and assembled into modules and arrays. A mono-crystalline silicon has a uniform molecular structure. Compared to non- crystalline materials, its high uniformity results in higher energy conversion efficiency - the ratio of electric power produced by the cell to the amount of available sunlight power- i.e. power-out divided by power-in.

The higher a PV cell's conversion efficiency, the more electricity it generates for a given area of exposure to the sunlight. Not only are they energy efficient, mono-crystalline modules are highly reliable for outdoor power applications.

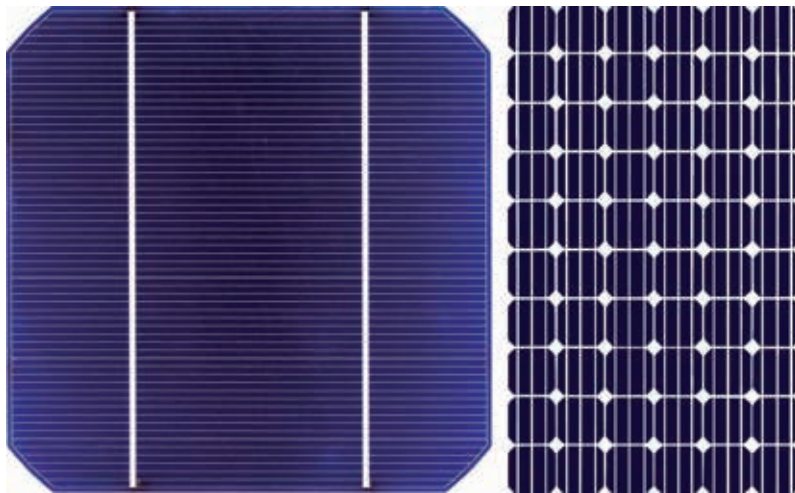


Fig 5 Mono-crystalline silicon cells

2.2.2 Poly-crystalline silicon

Consisting of small grains of mono-crystalline silicon, poly-crystalline PV cells are produced by slicing thin wafers from blocks of cast polycrystalline silicon. Another more advanced production approach is the “ribbon growth” method in which silicon is grown directly as thin ribbons or she-

ets with the approach thickness for making PV cells. Since no sawing is needed, the manufacturing cost is lower. The most commercially developed ribbon growth approach is EFG (edge-defined film-fed growth). Compared to mono-crystalline silicon, polycrystalline silicon material is stronger and can be cut into one-third the thickness of mono-crystalline material. It also has slightly lower wafer cost and less strict growth requirements.

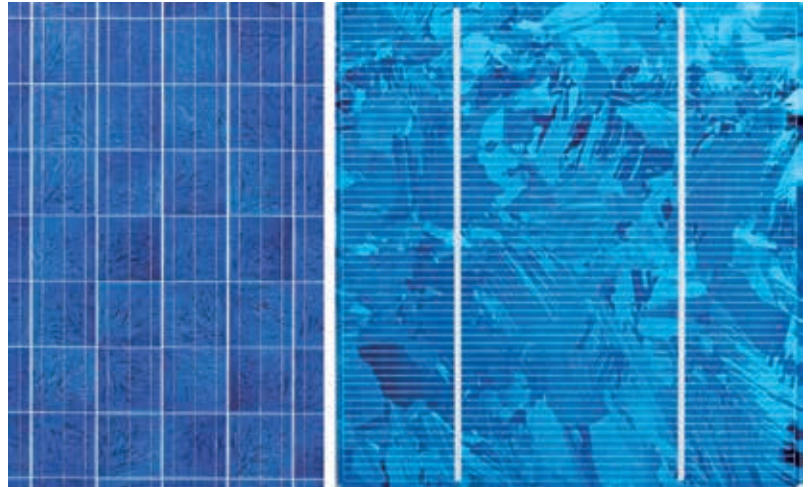


Fig 6 Poly-crystalline silicon cells

2.2.3 Gallium Arsenide (GaAs)

Gallium Arsenide is the highest performance solar technology currently available. A compound semiconductor made of two elements: gallium (Ga) and arsenic (As), GaAs, has a crystal structure similar to that of silicon. The advantage of GaAs is that it has high level of light absorbance which assures very high efficiency records, reaching more than 27% for the single cell and above 23 % for a solar panel.

These important advantage allows gallium arsenide cells to be competitive compared to silicon-based cells even if their price is consistently higher. Current researches have focused in finding the way to reduce the high production costs in order to introduce GaAs panels into the mass market.

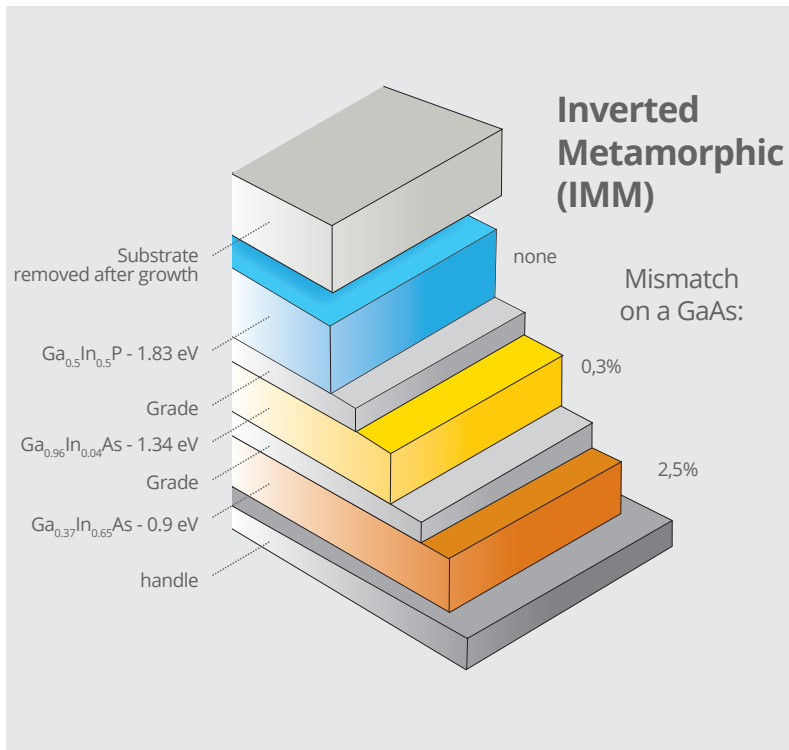


Fig 7a Gallium arsenide scheme

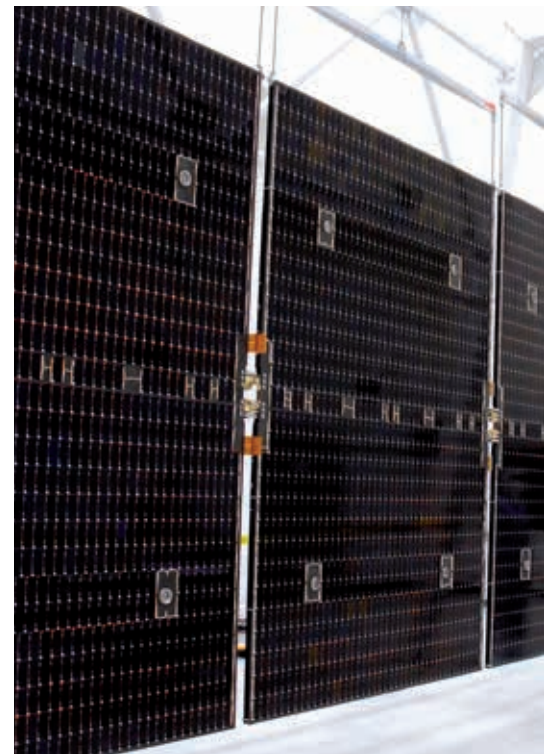


Fig 7b Gallium arsenide solar panels

2.2.4 Amorphous Silicon (a-Si)

Used mostly in consumer electronic products which require lower power output and cost of production, amorphous silicon has been the dominant thin-film PV material since it was first discovered in 1974. Amorphous silicon is a non-crystalline form of silicon, i.e. its silicon atoms are disordered in structure. A significant advantage of a-Si is its high light absorptivity about 40 times higher than that of mono-crystalline silicon. Therefore only a thin layer of a-Si is sufficient for making PV cells (about 1 micrometer thick as compared to 200 or more micrometers thick for crystalline silicon cells). Amorphous silicon (a-Si or a-Si:H) solar cells belong to the category of silicon thin-film, and have several advantages. First of all it requires much less silicon and the substrates can be made out of inexpensive



Fig 8 Plus-Energy house, Berlin

materials such as glass, stainless steel and plastic. These are the two major reasons why amorphous silicon solar cells have a great potential to become cheaper than mono- and polycrystalline solar cells. Moreover a flexible thin-film module can be placed on curved surfaces and can perform relatively well under poor lighting conditions.

2.2.5 Cadmium Telluride (CdTe)

It is a photovoltaic (PV) technology based on the use of a thin film of CdTe to absorb and convert sunlight into electricity. As a polycrystalline semiconductor compound made of cadmium and tellurium, CdTe has a high light absorptivity level as only about a micrometer thick can absorb 90% of the solar spectrum.

The major advantage of this technology is that the panels can manu-

factured at lower costs than silicon based solar panels. It is also easy to manufacture, as the necessary electric field which makes turning solar energy into electricity possible is generated from the properties of two types of cadmium molecules, cadmium sulfide and cadmium telluride. This means a simple mixture of molecules achieves the required properties, simplifying manufacturing compared to the multi-step process of joining two different types of doped silicon in a silicon solar panel.

Cadmium Telluride absorbs sunlight at close to the ideal wavelength, capturing energy at shorter wavelengths than is possible with silicon panels. The material is easily available, as Cadmium is abundant, produced as a by-product of other important industrial metals such as zinc. This avoids also the price swings that happen with silicon prices. Nevertheless, while price is a major advantage, Cadmium telluride solar panels currently achieve a quite low efficiency around 10.5%, which is significantly lower than the typical efficiencies of silicon solar cells. On the contrary to Cadmium which is relatively abundant, Tellurium is not. Tellurium (Te) is an extremely rare element in nature. Another negative issue concerns the high toxicity of Cadmium, being one of the top 6 deadliest and toxic materials known.

2.2.6 Copper Indium Diselenide (CuInSe₂, or CIS)

Systems produced with Copper Indium Diselenide belong to the thin film PV family. A polycrystalline semiconductor compound of copper, indium and selenium, CIS has been one of the major research areas in the thin film industry. The reason for it to receive so much attention is that CIS has the highest “research” energy conversion efficiency among all the existing thin film materials, but also came close to the research efficiency of the polycrystalline silicon PV cells, being its efficiency measured around 18-19 %. CIS is also one of the most light-absorbent semiconductors as 0.5 micrometers can absorb 90% of the solar spectrum.

Despite having the advantage on the CdTe, which is negatively affected by the problem related to the use of the heavy metal Cadmium and the scarce availability of Telluride, the development of CIS commercially remains behind the CdTe.

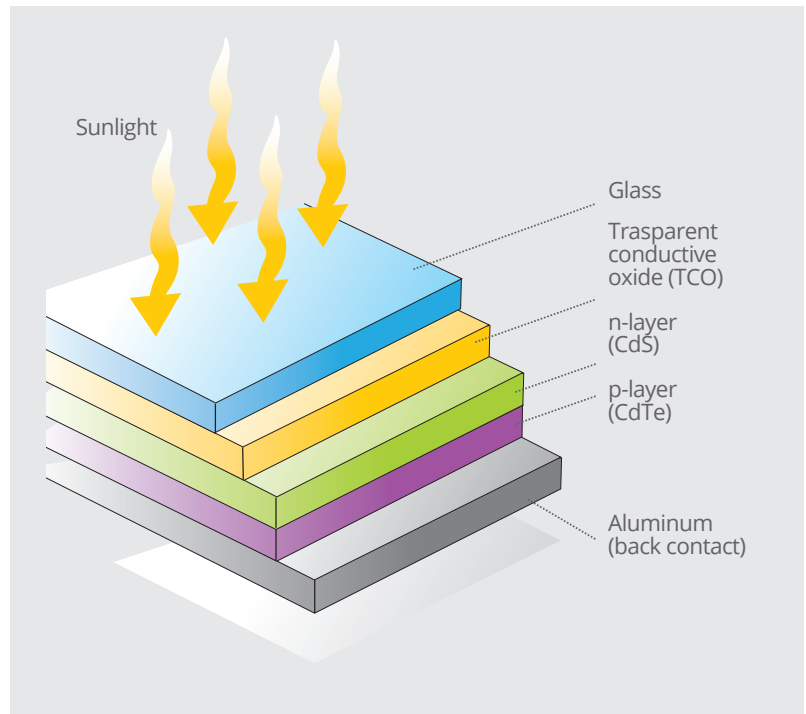


Fig 9 Copper Indium Diselenide

2.2.7 Graphene

Graphene is a material under study considered able to replace silicon. Because Graphene is pure carbon, its charge conductivity is very high, it is transparent, flexible and at the same time resistant. From the physical point of view, it consists in a two-dimensional molecule (just 0.35 nm thick) of carbon atoms capable of transporting electrons at a considerable speed. Conventional materials that turn light into electricity, like silicon and gallium arsenide, generate a single electron for each photon absorbed. Since a photon contains more energy than one electron can carry, much of the energy contained in the incoming light is lost as heat. Now, new research reveals that when graphene absorbs a photon it generates multiple electrons capable of driving a current. This means that if graphene devices for converting light to electricity come to fruition, they could be more efficient than the devices commonly used today.

The material can also work with every possible wavelength (there is no other material in the world with this behaviour), it is flexible, robust, relatively cheap, and can be easily integrated with other materials.

2.2.8 Organic PV

Organic PV seems to be the new focus of research, inverting the tendency of studying the best energy efficiency using oil derivatives, such as cotton and castor oil, for the production of coating in order to promote the use of renewable materials. Castor seeds generate a resin very similar to nylon, while cotton ensures the right solidity thanks to the cellulose fibre of which it is composed.

Very recently some mass production methods have been developed based on printing technologies which allow the manufacturing of decorative, organic solar panels. This implemented design freedom improves the range of applications of the panels on the surfaces of interior and exterior building spaces. In this case the solar panel can be only around 0.2 mm thick, including the electrodes and polymer layers where the light is collected. Furthermore, graphics can be printed to improve its visual appearance. The solar panels are manufactured with printing machines



Fig 10 Sheets of carbon composing Graphene

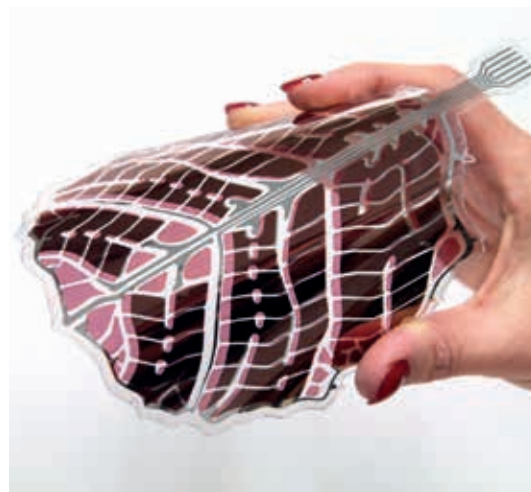


Fig 11, Fig 12 Organic PV "leaf"

based on conventional printing methods using the roll-to-roll method, which enables the rapid mass production of the products: the printing machine can produce up to 100 m. of layered film per minute. The manufacturing of the OPV cells is affordable; the material consumption is low, and after use, the OPV panels can be recycled. Even if organic solar panels a very interesting solution for building integration, being flexible and light, their efficiency is still quite lower compared to conventional, rigid silicon-based solar panels and its life time is not competitive.

2.3 Transparency

Modules with different transparency rates, 10%, 20% or 30% of transparency degree are available on the market giving the advantage to illuminate indoor with sunlight, avoiding at the same time UV- and infrared



Fig 13 Transparent solar panels

radiation. Most commonly they consist of transparent crystalline cells, very often are also modules with transparent back side and with standard crystalline cells. Another interesting solution is thin film transparent amorphous modules. Transparent modules can be used as window glazing in usual windows, sunspaces, they can be integrated into roofs etc. Quite often they are also a part of shading devices whether movable or not.

2.4 Size

PV systems are modular, allowing a great degree of flexibility in design and specification. In practice, the size of a system is almost always determined by the available space or the energy requirement of the property. The size of PV installation is depending on several factors:

- Geographic location
- Available space
- Yearly required energy
- Position of the installation. This will guarantee a particular efficiency depending on inclination and partial shading.
- Choice of PV modules, (certain solar PV modules generate more electricity per square meter than others)
- Available budget and incentives

2.5 Shape

PV modules come in a great variety of dimensions and forms, depending on the assembly of the cells composing it, practically without limitations. They can also be personalized, according to the offer of major companies.

New technologies, such as flexible PV films, can be shaped and adapted to all surfaces, opaque and transparent.



03

Pv Integration





3.1 Definition

PV Building Integration (BIPV) is a practice that allows the use of PV modules as architectural elements, being a collaborative part of the design of the fabric and having an architectural function and not just being an installation. It differs from Building attached photovoltaic (BAPV) regarded as add-ons to the buildings, hence not directly related to the building structures functional aspects. That is, BAPVs are not BIPVs, i.e. the BAPVs are not integrated into the outer building envelope skin, thus not replacing the traditional building parts as the BIPVs are doing.

PV modules can be defined integrated when their removal is compromising the functionality of the building envelope and the conceptual design of the building itself. (Basnet, 2012)

It is usually possible to do architectural integration, i.e., integrate the systems in an architecturally good way so that the aesthetics of the building is enhanced. However, it may always not be that easy to do building integration.

Most of the times, the PV or collector systems on the buildings are either architecturally integrated or building integrated or both. These systems doesn't have to be building integrated to achieve architectural integration. It can be further said that building integration is architectural integration but all architectural integration is not building integration. When the process of integration enhances the architectural quality of the building, it is called architectural integration. So, in a building integrated PV roof, the roof may be specially manufactured with PV already fixed as the external part of the roof. In case of architecturally integrated PV roof, PV modules can be laid as normal roofing element with normal construction techniques. In both the cases, the integration may add on to the aesthetics of the roof and the whole building and hence called architectural integration. Integration also doesn't mean that the PVs are used in such a way that they are not recognizable. It is not necessarily wonderful or important that the integrated PV (...) is 'hidden' and not shown. In practice, energy output of PV systems may have to be compromised over architectural integration. Which means, in an approach to use these systems in such a way that the building's architectural expression is enhanced; they may not be located in the best position, direction and orientation. It is neces-

sary to compromise but the best thing would be not to compromise. Due to practical reasons, there are compromises. We must be more innovative and creative enough to tackle this.

The terms component integrated and building integrated photovoltaics (BIPV) refers to the concept of integrating photovoltaic elements into the building envelope, establishing a symbiotic relationship between the architectural design, functional properties and economic regenerative energy conversion. The photovoltaic modules thus **replace conventional construction materials, taking over the function** that these would otherwise perform. Although this idea is not new, it is not widely harnessed due to the extensive planning and architectural challenges currently involved.

Building integration concerns the physical integration of a PV system into a building, with the emphasis of overall impression they give to the building. For the architect, the aesthetic aspect, rather than the physical integration, is the main reason for talking about building integration. The optimal situation is a physically and aesthetically well-integrated system. In fact, many examples of physical integration show a lack of aesthetic integration. Visual analysis of solar systems in buildings shows that the look of a poorly designed building does not improve, simply by adding a well-designed system. On the other hand, a well-designed building with a nicely integrated solar system will be accepted by everybody (Reijenga and Kaan, 2003).

Integration of PV is influenced and guided by certain criteria to achieve quality in the process. There exists number of architectural issues that needs to be taken into consideration while integrating these systems into buildings. These issues play very important roles to achieve quality architectural integration. For which, the fundamental aspects of building such as functional, constructive and formal aspects needs to be fulfilled (Probst and Roecker, 2011). Architectural integration quality of PVs and solar collectors can hence be defined as the result of their controlled and coherent integration simultaneously under functional, constructive and formal (aesthetic) points of view (Probst and Roecker, 2011).

3.2 PV - Integration Methods

3.2.1 Energy efficiency integration approach of BIPV

The reduction of energy consumption and the use of renewable energy are becoming more and more important in terms of sustainable development in the field of architecture. In the age of Nearly-Zero Energy Buildings, the architect has the obligation to inform building owners about the advantages of energy-efficient buildings that can dramatically reduce the energy demand (with relative environmental and economic costs) and run with renewable energy. Thus, the architect has required to possess the knowledges and the necessary tools to promote BIPV. It is necessary to understand and consider the possibilities, the obligations, the benefits and the drawbacks of a BIPV project. If BIPV is properly considered since the early design phase, the architectural design can become the way for ensure a better integration of PV from the aesthetic, constructive, energetic and economic perspective. Given the growing popularity of PV systems, it is necessary to prevent their indiscriminate use in building. It is therefore appropriate that professionals working in the construction process know they can rely on the most innovative offer of PV technology: the constructive and architectural integration of photovoltaic elements (BIPV). Being both a part of the building envelope/system and a power generator, BIPV systems permit to reduce the initial investment costs, the material and the necessary labor for the set up in comparison to a traditional construction where PV modules don't replace traditional building elements. BiPV is a multi-functional technology that can be optimally adapted on both new constructions and existing buildings. This allows the BIPV technology to be one of the sectors of the photovoltaic industry with the highest growth rate.

3.2.2 Multifunctional and aesthetic integration

The BiPV concept, as typical in building and architecture, involves two complementary aspects.

- The first one is the multi-functionality of the solar component that is the functional/constructive integration.
- On the other side there is the aesthetic integration that is the architectural quality of integration.

A functional integration refers to the role of PV modules in the building. For this reason we can speak about multifunctionality or double function criteria. Photovoltaic modules are considered to be building integrated, if they consist in a building component. The building's functions in the context of BiPV may be one or more of the following aspects:

- weather protection: rain, snow, wind, hail, UV radiation;
- mechanical rigidity and structural integrity;
- thermal and solar protection such as shading/daylighting;

The aesthetical integration on the other hand refers to the building concept and appearance and is more difficult to be defined in a unique way. The aesthetical (morphological-figurative) integration has to be understood as the PV capability to define the building architectural language. In contemporary architecture the image is one of the first factors of recognizability of buildings and a new specific path of innovation is more and more linked to "Solar Architecture".

Anyway, any aesthetical definition cannot determine with certainty and objectivity what is beautiful in terms of integration, but can help architects and building owners to define useful references:

- the position and dimension of the modules have to be coherent with the architectural composition of the whole building
- the PV module visible material, surface texture and color should be compatible with the other building skin materials, colors and textures that they are interacting with.
- module size and shape have to be compatible with the building composition grid and with the various dimensions of the other facade elements.
- jointing types must be carefully considered while choosing the product, as different jointing types underline differently the modular grid of the system in relation to the building.

3.2.3 PV integration by building elements (roof, façades and openings)

On the roof PV can be integrated by:

- exchanging part of the existing roof with PV cells assembled directly on the tiles or modules that have the same dimension and shape

of the existing building elements they integrate with. Tile products may cover the entire roof or selected parts of the roof. They are normally arranged in modules with the appearance and properties of standard roof tiles and substitute a certain number of traditional roof tiles, thus also enabling easy retrofitting of roofs. The cell type and tile shape varies: some tile products may resemble curved ceramic tiles and will not be as area effective due to the curved surface area, but may be more aesthetically pleasant.

- Using a transparent or semi-transparent PV panel in order to create a full transparent or a shading roof. Shapes can be very variable, from flat to tilted to round.



Fig 1 Academie de Mont Cenis, Emscher Park, Ruhr

- Installing foil products, which are lightweight and flexible, allowing easy installation and prevailing weight constraints for roofs. The PV cells are often made from thin-film cells to maintain the flexibility in the foil and the efficiency regarding high temperatures for use on non-ventilated roof solutions. PV foil products have a low fill factor due to both the low efficiency and the large solar cell resistances of thin-film cells. However, it is possible to vary the degree of inclination of the product to a great extent providing flexible solutions.

In general, in BIPV practice the most widely used technologies between the roofing elements are mono-crystalline in cold climates and poly-crystalline in hot Mediterranean regions, particularly on tiles. Tiles are usually quite small, so the high efficiency of technology must be increased.

On external vertical walls PV can be used in different ways as external façade:

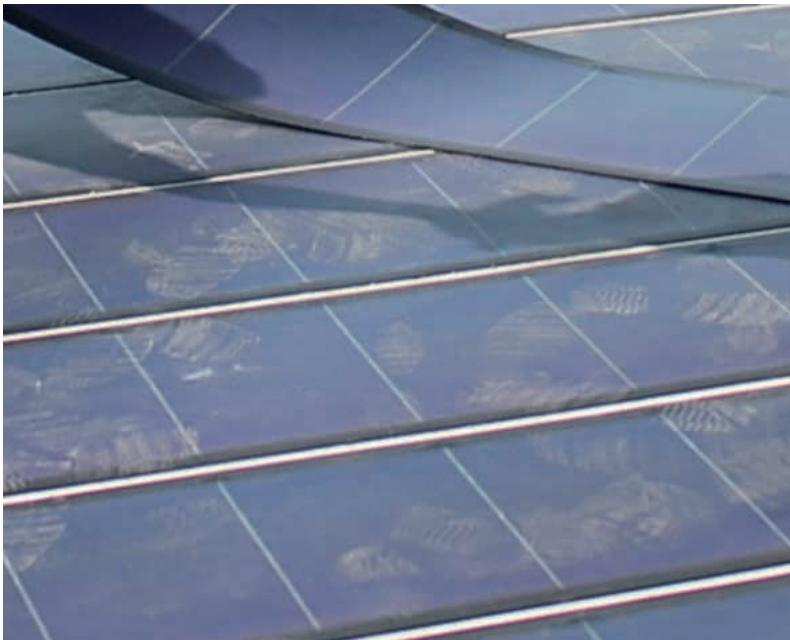


Fig 2 Flexible thin film PV

- external finish/film, fully integrated in the wall. In this case the PV surface needs to guarantee to be mechanical and thermal resistant;
- ventilated façades: PV-ventilated façades are double façade constructions which combine the advantages of cooling the PV modules using ambient air. Ventilating building integrated photovoltaic façades are advantageous both from an electrical and thermal point of view.

The air circulation behind the PV panel lowers module temperatures and thus improves the electrical performance.

Ventilated PV façades also imply lower wall or glazing temperatures behind the module and consequently lower cooling loads in summer. Furthermore, a controlled airflow behind the PV façade leads to potential uses of the warm air for winter preheating.

- Curtain walls: Curtain walling systems are a well-established technology used in numerous projects such as city centre offices. The mullion/transom stick system is the most common. Vision areas



Fig 3 Ventiladed PV façade. Built for Solar Decathlon Europe 2010

are normally double-glazed and non-vision areas are either opaque glass or insulated metal panels. PV modules can be incorporated easily as factory-assembled double-glazed units. The outer panel might be laminated glass-PV-resin-glass and the inner pane, glass, with a sealed air gap in between; the overall thickness of the module would typically be under 30mm. Numerous design options are available. For example, a façade could consist of a combination of glazed areas for vision and opaque PV panels or it could have PV modules with opaque areas and transparent ones.

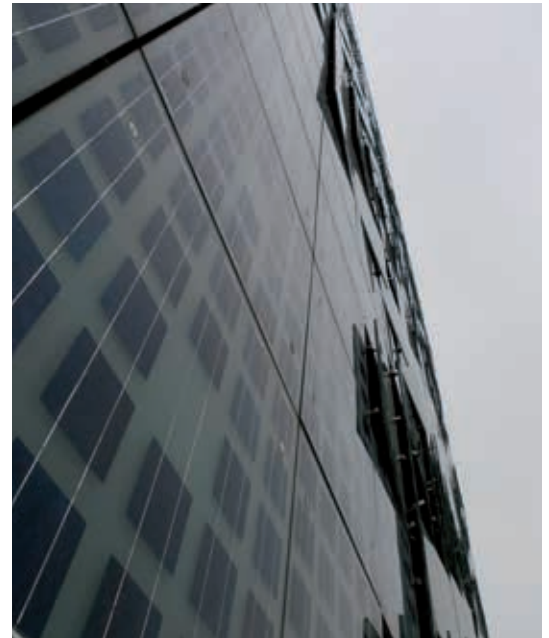


Fig 4a, 4b Curtain wall PV system

- Rain-screen cladding systems: they normally consist of panels (often coated aluminium) set slightly off from the building (for example on cladding rails) to allow for drainage and ventilation. As such they are very suitable for PV integration. The ventilation gap (which needs to be adequate, e.g. 100mm or more if possible, and unobstructed) has the beneficial effect of re-

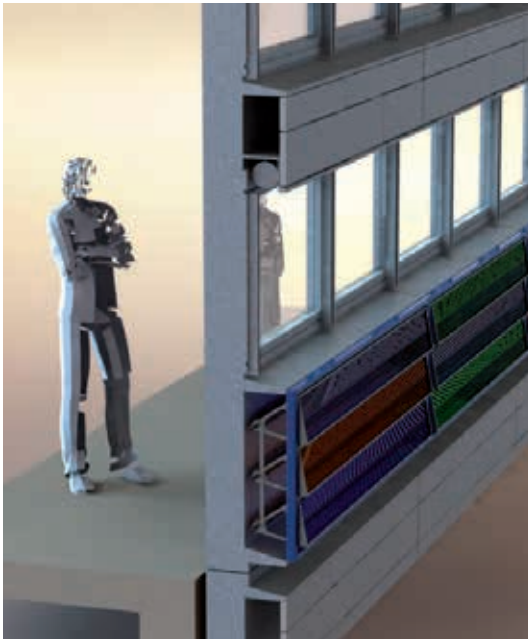


Fig 5a, 5b, 5c Proposal for integration of CPV technology into buildings



ducing temperatures, thus enhancing performance; it also provides space for cable routes.

- Warm façades: it is a curtain wall with an unventilated warm cavity wall attained by the water and air tightness of the insulated outer skin-façade. The outer skin of the warm façade is made up of insulated spandrel panels and insulated transparent components. Both the spandrel panels and transparent components are attached to the inner wall by profiles. The profiles are equipped with a thermal insulator so that a cold bridge (thermal leak) is prevented. The spandrel panels and transparent components are jointly installed at shell distance to the load bearing building skeleton. The joint installation provides the possibility for large component mounting.
- Cold façades: it is a curtain wall with a cold ventilated cavity wall. The ventilation in the cavity wall is achieved by open seams in the façade, which allow ambient air to enter the cavity. The façade elements at the outside of the cavity wall act as a raincoat and prevent soaking of the insulation material. The inside skin of the cavity wall is airtight, insulated but damp open. The cold façade is usually

mounted using the stick system or ladder mounting technique.

- Solar cell glazing products: they provide a great variety of options for windows, glazed or tiled façades and roofs. Different colours and transparencies can allow to obtain many different aesthetical results. The solar cell glazing modules transmit daylight and serve as water and sun protection. The distance between the solar cells (normally 3 - 50 mm) depends on wanted transparency level and the criteria for electricity production. The space between the cells transmits diffuse daylight. Hence, both shading and natural lighting are provided while producing electricity. Very adapted for cold climates, this technology poses the difficulty of finding the right compromise between solution and energy output, avoiding the overheating by



Fig 6 Meyer Hospital, Florence, Italy

greenhouse effect in Mediterranean countries.

- Solar shadings: the integration of PV systems as external solar shading devices is one of the most effective way to control the internal daylight and thermal conditions of a building.

It provides solar heat gain prevention from passing into the building, minimising ventilation requirements and reducing cooling loads with the plus of electric energy production. If a controllable system is installed, adjustable louvres track the position of the sun optimizing PV production, thereby optimising the avoidance of overheating. Equally, in winter the louvres may be adjusted in such a way that the building benefits from the heat from the sun, and they can be closed at night reducing heat loss.



Fig 7 Photovoltaic brises-soleil



Fig 8 Museu de la Ciència i de la Tècnica de Catalunya (mNACTEC), Terrassa



Fig 9 Academie de Mont Cenis, Emscher Park, Ruhr



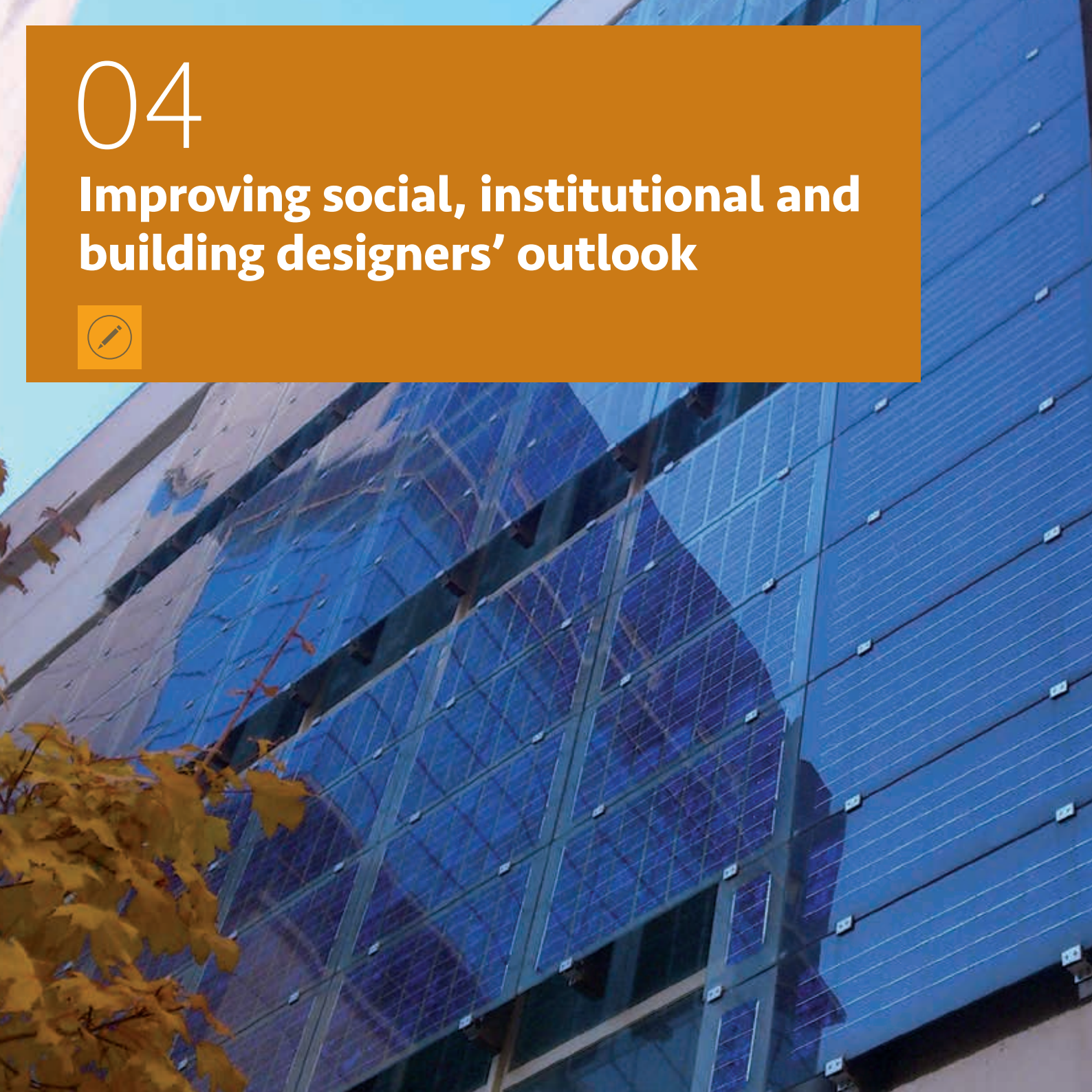
Fig 10 Academie de Mont Cenis, Emscher Park, Ruhr

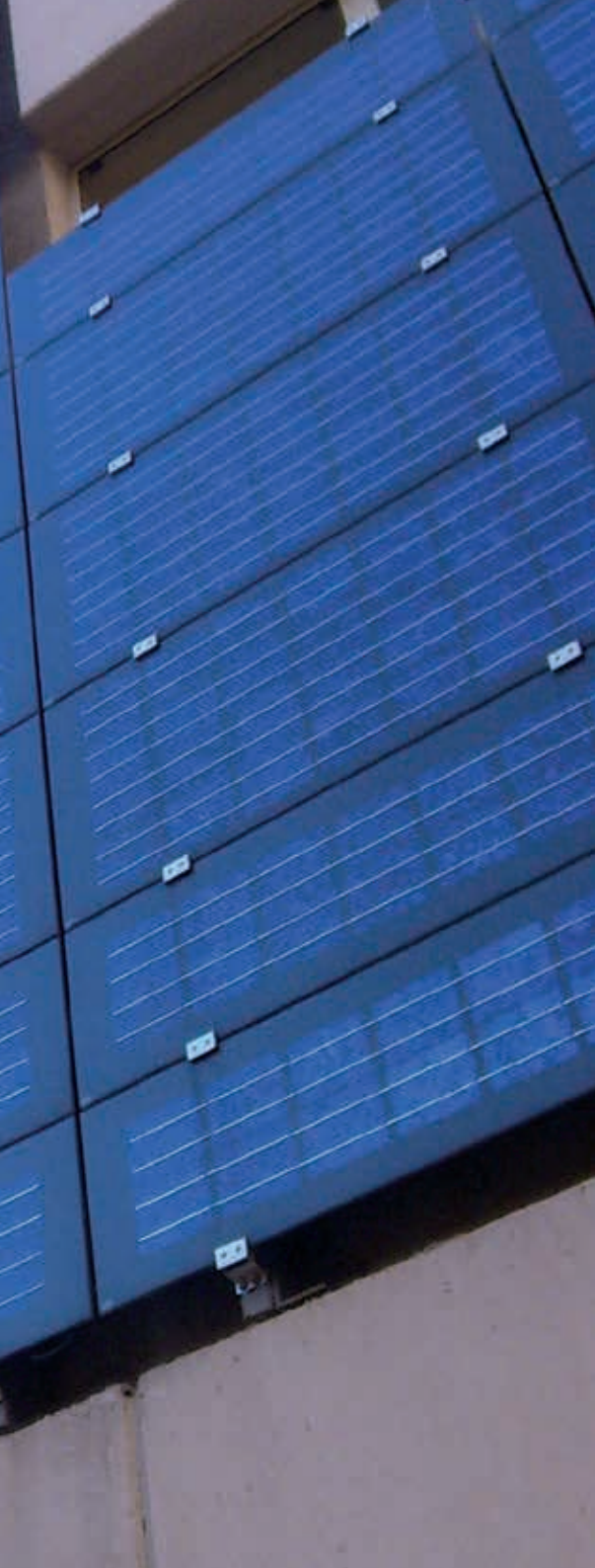
- Atrium/skylights: PVs can equally be integrated as multifunctional elements in transparent roof structures or atriums that allow controlled light into the interior. As semitransparent roof units, they can protect the building from heat, sunlight, glare and the weather. One way of integration would be to place small sized PV cells on the atrium glass creating transparent gaps between them to allow controlled daylight into the interior of the building. Well designed PV integrated atriums may also be a strong feature of the building when viewed from the interior.
These glazing systems, though best suited for small capacity PV systems, can be very visually appealing and provide great visibility. Because skylight, atrium and greenhouse glass is often heavily tinted to minimize glare, semitransparent PV glazing can make a good substitute.

The BIPV module products are somewhat similar to conventional PV modules. The difference, however, is that the BIPV modules are made with weather skin solutions. Some of the products may replace various types of roofing, or they fit with a specific roof solution produced by its manufacturer. These mounting systems increase the ease of installation. There is a large amount of products on the market and some of them are promoted as BIPV products without in fact functioning as weather skins, whereas other products are not very specific on how they are actually mounted, which leads to uncertainty whether they are BIPVs or BAPVs. Some of the BIPV module products are pre-made modules with thermal insulation or other elements included in the body.

04

Improving social, institutional and building designers' outlook





4.1 BIPV as an added value for building

The integration of PV systems into buildings replacing roofing elements, windows, shadings and glazed façades offers the opportunity for cost reduction by substitution of conventional building materials with PV materials. When compared to glass, steel, stone, or other more conventional cladding materials, installing BIPVs can add only a marginal extra costs to the overall construction costs. On the other hand, the photovoltaic system allow to get a certain number of benefits in economic and environmental terms, far from negligible:

- 1 They are nowadays accessible in terms of costs, and in many countries they are subject to incentives
- 2 Give immediate economic savings given by the production of electricity.
- 3 Contribute to a drastic reduction of atmospheric CO2 emissions.
- 4 Increase the economic value of the property where the equipment is installed.
- 5 Don't need particular expensive maintenance

4.2 Relevance of different actors in the integration process

BIPV is the result of the interaction between several actors: the building owner, the designer-architect, the eventual financier, the building constructor, the electrician, the local administration. These figures all cooperate in putting together a functional and well integrated PV system. None of them can be missed or substituted, as each of them has a very definite task in the process.

4.3 The role of architects and building designers

Including PV in building projects, to a large extent, depends on the knowledge of the architects and designers about this technology (as a building material), its aesthetic qualities, construction detailing, weathering, durability, solar access limitations, performance, products, warranties and cost. The designer is also interested in how PV can be made part of a ethical design solution that includes the energy equation

together with the overall building aesthetics. Architects should advise clients about such options and need to be well informed about BIPV economics, including value-added benefits, greenhouse gas emission avoidance, interconnection with the grid or storage, reliability and risks associated with system failures. While its important that architects be aware of all these issues, their technical information needs may be minimal. A greater emphasis, especially during the early concept stage is more likely to be on the aesthetic, construction, durability, weathering and solar access limitations.

4.4 Improving citizens' consciousness

The owner/client of a building project takes the final decision on whether PV is to be part of the overall design, irrespective of the scale of the project. This decision is governed by factors such as cost, paybacks, value added benefits, in terms of how the PV is applied as part of the overall energy solution, and building aesthetics.

A critical factor often is the owner's commitment to sustainable building and to its long-term environmental impact. In such instances, cost may have a lesser role to play in decision making, however, the owner in all cases shows a commitment to environmental responsibility. Building owners clearly need to be convinced by those advising them about most aspects of BIPV:

- **electrical** (kWh generated; synergies with other forms of energy, such as heating and cooling, through added insulation or shading; reduction in demand of utility electricity; power in times of emergency; grid support for rural lines; reduced transmissions and distribution losses; voltage control; smoothing loan fluctuation);
- **environmental** (consumer satisfaction for those that desire environment-friendly products; significant energy generation over life time; reduced CO2 emissions; reduced acid rains and lower smog levels; reduced power stations land/water use; reduced impact of urban development);

- **architectural** (architectural intrinsic significance and aesthetics; substitution of building components, multi-function potential for insulation; waterproofing; fire protection; wind protection; acoustic control; day lighting; shading; thermal collection and dissipation; aesthetic appeal through colour, transparency, non reflective surfaces; reduced building maintenance and roof replacements);
- **socio-economic** (enhancement of the building's value by the PV presence; prestige and marketing opportunities; new industries, product and markets; local employment for installation and servicing; local choice, resource use and control; short construction time; improved implementation by modularity; reduced fuel imports; urban renewal; rural development; reduced fuel transport costs and pollution from fossil fuels use in rural areas; symbol for sustainable development and associated ecological education);
- **security of supply** (the continuous increase of electricity consumption overloads power stations and distribution grids which influences the supply security and the power quality. PV systems are characterized by relatively small generation units located nearby the consumers that use the locally available energy resources. This enhances the reliability of the grid and also enhances power quality, which is increasingly important for electronic equipment).

An integrated building energy system is included in the construction budget. Owners shall be advised that electricity generated by the BIPV systems reduces the amount of electricity purchased from the grid, and consequently the building operating costs.

A BIPV system can also save the building owner money by reducing construction costs, enhancing power quality and power reliability, and (in some countries) providing tax incentives and credits. The combined savings may occur in a variety of ways that will affect the investor's entire fiscal portfolio performance.

Commercial building owners may gain through BIPV a value related to the Company's strategic goals, business interests, or managerial mission.

With a multifunctional BIPV system, additional costs and benefits may be sometimes hidden or not obvious, due to accounting methods, but still directly or indirectly affect budgets. An organization, for example, may be able to assign a credit or value for BIPV for environmental emissions reduction if they can be quantified, valued, and even traded. However, if an economic effect cannot be captured or understood by a decision-maker, it is generally not included in the investment analysis.

Even if some benefits of BIPV systems are subjective and difficult to quantify, for the building owner, a considerable value of a BIPV system may be anyway associated with a positive image, public perception, or impact on the built environment when PV technology is installed.

4.5. Integration by building age (historical/recent)

Special care has to be given to the integration made on historical buildings. These will include all buildings listed as historical after each country's legislation, and will also include all buildings that, even if not officially listed, have preserved characters and details of particular interest.

In general, when installing a new system on an existent building it is important to:

- Carefully consider the application of energy-conscious design practices and/or energy-efficiency measures to reduce the energy requirements of the building. This will enhance comfort and save money while also enabling a given BIPV system to provide a greater percentage reduction to the grid load.
- Design for the local climate and environment: designers should understand the impacts of the climate and environment on the array output. Cold, clear days will increase power production, while hot, overcast days will reduce array output;

Designers should consider that:

- surfaces reflecting light onto the array (e.g., snow) will increase the array output;
- arrays must be designed for potential snow- and wind-loading conditions;

- properly angled arrays will shed snow loads relatively quickly;
- arrays in dry, dusty environments or environments with heavy industrial or traffic (auto, airline) pollution will require washing to limit efficiency losses.
- Address site planning and orientation issues: early in the design phase, ensure that solar array will receive maximum exposure to the sun and will not be shaded by site obstructions, such as nearby buildings or trees. It is particularly important that the system be completely un-shaded during the peak solar collection period. The impact of shading on a PV array has a much greater influence on the electrical harvest than the footprint of the shadow.
- different array orientation can have a significant impact on the annual energy output of a system, with tilted arrays generating 50%-70% more electricity than a vertical façade.
- it's possible to integrate day lighting and photovoltaic collection by using semi-transparent thin-film modules, or crystalline modules with custom-spaced cells between two layers of glass. Designers may use PV to create unique day lighting features in façade, roofing, or skylight PV systems. The BIPV elements can also help to reduce unwanted cooling load and glare associated with large expanses of architectural glazing.
- they can incorporate PV modules into solar shading devices: PV arrays conceived as "eyebrows" or awnings over view glass areas of a building can provide appropriate passive solar shading. When solar shading devices are considered as part of an integrated design approach, chill capacity can often be smaller and cooling distribution reduced or even eliminated.
- they can choose between a grid connected and a stand-alone system: the vast majority of BIPV systems will be connected to a utility grid, using it as storage and backup. The systems should be sized to meet the goals of the owner-typically defined by budget or space constraints; the inverter must be chosen with an understanding of the requirements of the utility.
- For those 'stand-alone' systems powered by PV alone, the system, including storage, must be sized to meet the peak demand/lowest power production projections of the building. To avoid over sizing

the PV/battery system for unusual or occasional peak loads, a backup generator is often used.

- If the peak building loads do not match the peak power output of the PV array, it may be economically appropriate to incorporate batteries into certain grid-tied systems to offset the most expensive power demand periods. This system could also act as an uninterruptible power system (UPS).
- Provide adequate ventilation: PV conversion efficiencies are reduced by elevated operating temperatures. This is truer with crystalline silicon PV cells than amorphous silicon thin-films. To improve conversion efficiency it is appropriate to ensure an air gap underneath the solar cells in order to allow ventilation behind the modules to dissipate heat.
- Evaluate using hybrid PV-solar thermal systems: as an option to optimize system efficiency, a designer may choose to capture and use the solar thermal resource developed through the heating of the modules. This can be attractive in cold climates for the pre-heating of incoming ventilation air.
- Consider the inclination of the BIPVs, as the solar cells necessarily need to follow the roof inclination (or the wall for that matter) to be integrated solutions.
- Remember that solar cells can be incorporated into the façade of a building, complementing or replacing traditional view or spandrel glass. Often, these installations are vertical, reducing access to available solar resources, but the large surface area of buildings can help compensate for the reduced power.
- Judge the idea that photovoltaic may be incorporated into awnings and saw-tooth designs on a building façade. These increase access to direct sunlight while providing additional architectural benefits such as passive shading.
- Be aware that the use of PV in roofing systems can provide a direct replacement for conventional metal roofing, allowing the elimination of asphalt waterproofing insulation.
- Using PV for skylight systems can be both an economical use of PV and an attractive design feature.
- Professionals: the use of BIPV is relatively new. Ensure that the de-

sign, installation, and maintenance professionals involved with the project are properly trained, licensed, certified, and experienced in PV systems works.

Existing or historic buildings, like new buildings, offer a broad range of possibilities for PV systems integration. However, installations on existing buildings unavoidably tend to be more uneven than on new buildings, since they have to comply with an existing situation. As standardized products are often not applicable, the situation calls for innovative approaches with custom made products (Hermannsdorfer and Rub, 2005). It is always not an easy task to make integration in an existing building due to various constraints. Integration task will have to be planned according to the situation observed on site, which varies from building to building.

In case of particularly important historical buildings, it can happen that the PV systems may have to be integrated somewhere else other than the building itself. This means that annexes to the property can be used for BIPV or the application on service buildings such as garages and deposits can be considered as alternative.

05

BIPV performance and sizing





5.1 The Physics of the Photovoltaic Effect

The photovoltaic solar panel can be defined as a device capable of converting the energy possessed by the solar radiation into electrical one. If we consider that the solar radiation is almost inexhaustible and the diffusion of electric appliance is on the rise, it is clear the importance of PV technology in the RES scenario.

The use of photovoltaic panels applied to buildings has shown to be an extremely effective strategy, even if it has been pushed by the national incentive campaigns. Photovoltaic technology needed these incentives because both the production costs of the panels were very high and the efficiency of the panel is intrinsically low. A PV panel is in fact able to convert theoretically only up to 20% of all the energy that it receives from the sun into electrical energy. This means that if, in optimal conditions, the panel receives 1000 W/m^2 of solar energy, it produces up to 200 W/m^2 of electricity. Therefore for 1 KW of power it is necessary to install more than 5 m^2 . In the last ten years the costs of PV panel were reduced more than by half and now 1 KWp comes to cost more or less 2.500,00€. Taking into account these considerations, it is evident how important is the rational integration of these components in the building system, in such a manner to ensure optimum operation. The use of this technology is a interesting exercise in design of facades and roof of a building in relation to the maximum uptake of solar energy panels and consequently a function of the path of the Sun and its orientation.

The great advantage of photovoltaic technology is its ease of operation and longevity. A photovoltaic panel has no moving parts and is extremely resistant. It is substantially constituted by silicon material hardly degradable. The principle of operation of a photovoltaic panel is based on the property that have the materials so-called "semiconductor" to excite the electrons of the outer atomic orbital if exposed to light radiation. The semiconductor material most widespread in nature is silicon, which is widely used for the PV panels. Silicon has 4 electrons in the last orbital. When a photon with appropriate energy (equal to $e = h\nu$, where h is the Planck constant and ν the frequency of solar radiation) hits an electron on the outer orbital, it gives it an amount of energy sufficient to blow it up into a higher energy level and take it from valence band to the conduction one.

However, to create a flow of electrons, that is, an electric current, it is not sufficient to excite an electron of the silicon, but it is necessary to create a field of electric potential within the material. If this does not occur, the electron naturally undergoes the effect of “recombination”, falling again in the valence band of the atom that regains its original configuration.

The effect of recombination is one of the major cause of the low efficiency in converting solar energy into electricity. The other fundamental reason lies in the fact that not all the Solar radiation is able to properly excite the electrons of a semiconductor. The photons’ energy must be comprised in a well determined range.

As said above, the excitation of peripheral electrons of the silicon atoms should not be sufficient to create an electric current, if there were no electric field capable of moving the electrons from one face of the panel to the other. This is generated by mixing, or, as usually said, by doping the silicon with particular substances.

The pure silicon has a crystalline tetrahedral structure. Each atom has four bonds with adjacent atoms to which it is constrained. The silicon is doped in the upper part with the phosphorus (P, $Z= 15$) and in the lower part with boron (B, $Z= 5$).

Boron has three electrons in the last orbital, then, inserted into the crystal lattice of the silicon atom, the latter has a valence electron not combined. Otherwise phosphorus, which has five electrons in the last orbital, entering the lattice has a not combined electron. The electrons free from the silicon bond attract those of phosphorus weakly bound to the nucleus toward the P -doped, i.e. to the bottom side of the cell. This creates what is called a P-N junction.

The balance of the bonds is thus restored, but the balance of the charges is interrupted. The phosphorus electrons migrating have created an imbalance of negative charges at the bottom of the cell. This means that it creates a field of electric potential able to move the electrons liberated by the photovoltaic effect. Those naturally will move towards the top of the cell, positively charged. The atoms of silicon left by the electrons excited by solar radiation will attract new ones from the bottom of the cell. If the two faces of the cell are connected by a conductor, it will create a flow of electrons (electric current) through this, capable of powering a load connected.

The component is completed by a layer of titanium oxide to reduce the reflection of sunlight and to let the cell absorb as much radiation as possible. The cell has a thickness not exceeding 0,4 mm. It remains to understand what happens to the solar radiation not converted into electricity. This is converted into heat which raises the temperature of the panel and is then re-radiated into the environment.

5.2 Assessing energy performance of BIPV

From the initial planning stage of a BIPV, it is important to consider in which part of the building solar panels might be sited. This requires to understand the climate conditions at the site, the way in which the sun's path travels across the sky during different seasons of the year (depending on latitude) and the building surfaces that are likely to receive high levels of solar exposure without too much interference from shade.

Access to adequate direct sunshine is important if high power outputs are to be achieved over a year. But there is flexibility in determining the position that can allow the solar photovoltaic panels to work the better as possible.

In the northern or southern shores of Mediterranean basin, as well as in Middle East regions, building surfaces that have a southerly or horizontal orientation will be exposed to good solar irradiation. As a rule of thumb, the optimum solar panel angle is one that is orientated true south and tilted at the latitude angle of its location. For example, Cagliari latitude is 39° N so a solar panel orientated true south and tilted 39° from the horizontal would be desirable to achieve maximum annual solar exposure. This is not always true since some local parameters (for example frequent cloudiness in given periods) can influence solar cumulative radiation. For those reasons for Cagliari a tilt angle of 30° is suggested.

Solar panels do not have to be optimally orientated to gain adequate outputs. Invariably, compromises with building design features, such as roof angle will be required. For instance, the internal comfort demands of the building and time of use tariffs may favour systems that shade south-westerly exposed surfaces and generate power in the

afternoon to reduce the need for artificial air-conditioning and peak load power purchases. This is particularly relevant in commercial buildings.

For most PV technologies, except amorphous silicon, the hotter the air temperature the lower the efficiency. PV modules work very well during high sun but relatively low ambient temperatures (eg. below 25°C). They generate direct current (DC) electricity and this power is rated by the manufacturer against Standard Test Conditions (STC). STC measures panel performance in artificial conditions. It replicates ambient air temperature of 25° C, solar irradiation intensity of 1000 W/m² and half times the thicknesses of the earth's atmosphere at the equator. This is comparable to a clear noon day at approximately 40° latitude. Modules may be rated as 100 Watts under STC and fall within actual performance of +/-5%. Given that Mediterranean basin and middle east regions experiences a high number of days with air temperature above 25° C, there is likely to be frequent decreasing of power output, especially during the height of summer. In addition, when operating on a roof or flat surface, PV modules can reach an internal temperature of between 50-75°C, causing further loss of performance.

Consequently, it is important to consider the climatic influence on different PV types and where they are likely to be sited. Natural ventilation can be used through good design to cool the PV modules to a more desirable operating temperature. This is particularly true for PV walls. The BIPV can be designed to draw hot air through and out of the top of the building, thus providing a cooler environment in which panels can operate. Amorphous silicon modules may be preferred in high temperature applications, despite their lower overall efficiency, since their performance is not as sensitive to temperature.

PV-cell temperatures are very difficult to measure since the cells are tightly encapsulated in order to protect them from environmental degradation. The temperature of the back surface of PV modules is commonly measured and used in place of the cell temperature with the assumption that these temperatures closely match. From a mathematical point of view, correlations for PV-cell operating temperature (T_c) are either explicit in form, thus giving T_c directly, or implicit, i.e. involve variables such as cell efficiency or heat transfer coefficients,

which themselves depend on T_c . In the latter case, an iteration procedure is necessary to calculate the cell temperature. A lot of models for PV-cell temperature evaluation can be found in literature. They include explicit and implicit models. One of the simplest and most widespread method to calculate T_c is given by equation (1).

$$T_c = T_a + \frac{G_m}{800} (\text{NOTC} - 20) \quad (1)$$

Where T_c is the cell's temperature, T_a is the air temperature ($^{\circ}\text{C}$), G_m is the solar radiation (W/m^2) and NOTC is the Normal Operating Cell Temperature ($^{\circ}\text{C}$). Once T_c is known the decrease of performance can be calculated by eq. (2).

$$\frac{PVP_{T_c}}{PVP_M} = 1 - \text{PTC} \cdot (T_c - 25) \quad (2)$$

Where PVP_{T_c} is the power of PV module at T_c temperature, PVP_M is the maximum power of the module (i.e. in Standard Test Conditions) and PTC is power temperature coefficient. It depends on the type of panel. The values given in the following refer to a typical poly-crystalline module.

High temperature can affect also the conversion of DC/AC by the inverters. In particularly hot regions it is necessary to cool down inverters rooms to improve their efficiency. It however involves an electricity consumption that should be subtracted by the production of the PV system. Another reducing factor is the dust deposition that can obstruct the correct working of panels. In some regions close to desert area it can be a serious issue. So if the data are available it has been included in the assessment of the production potential.

Catalonia Region - Spain

Since Catalonia is located roughly between latitudes 40,3° and 42,5° North, PV panels facing South and with a tilt angle of approximately 41° are the best design in terms of annual electricity production. During winter higher inclination would lead to slightly better production. However, being that 2/3 of annual energy are produced during summer semester (April to September), then a tilt angle close to place latitude is advisable to maximize annual energy yield. Figure 1 below shows differences on monthly solar radiation by different orientation and angles in Catalonia. Best inclinations are those close to 41°, whereas horizontal and south inclinations are those allowing the maximum radiation exposure in summer and winter respectively.

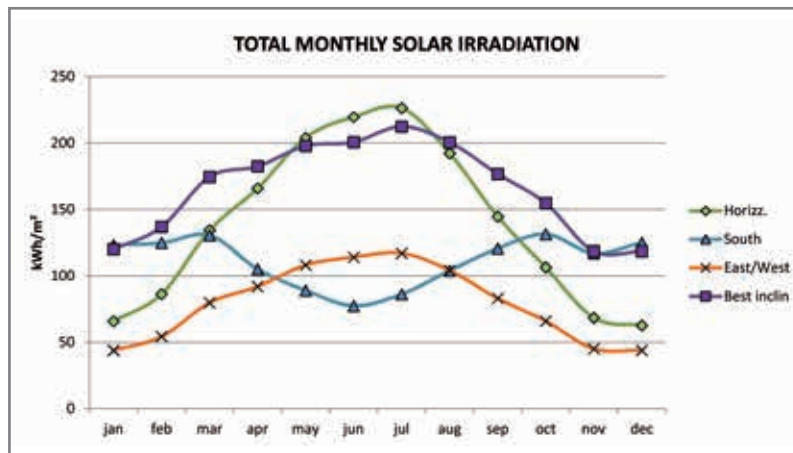


Fig 1 Global solar radiation by different orientation and inclination

Figure 2 below depicts the percentage of reduction of solar radiation by different orientations and tilt angle from the optimum. As it can be seen from the figure, solar panels installation can be flexible in both, inclination and tilt angle without reducing dramatically the plant performance. It is advisable to reduce tilt angle for those PV generators not facing the best orientation (South). Thus, a PV installation with 30° tilt angle can perform up to 90% even when

deviation from optimum (South) is as high as 45° (East or West). Best tilt inclination is not only allowing for a better radiation exposure but also a better temperature performance of the solar panels according to Figure 3, percentage of reduction of PV production due to cell temperature.

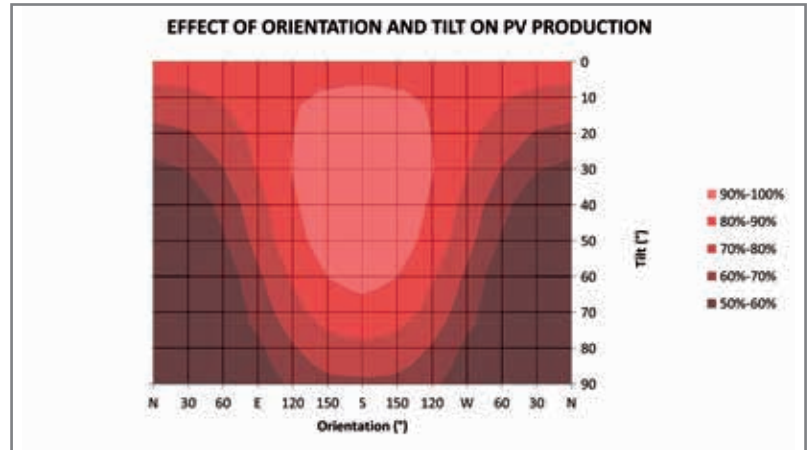


Fig 2 Percentage of output reduction by orientation and inclination

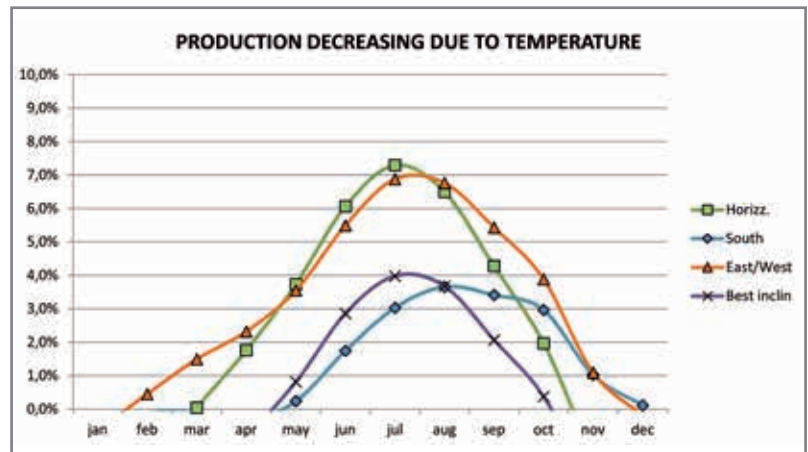


Fig 3 Percentage of output reduction due to temperature by orientation and inclination.

Alexandria Region - Egypt

In the following the data regarding solar irradiation in Alexandria region are given.

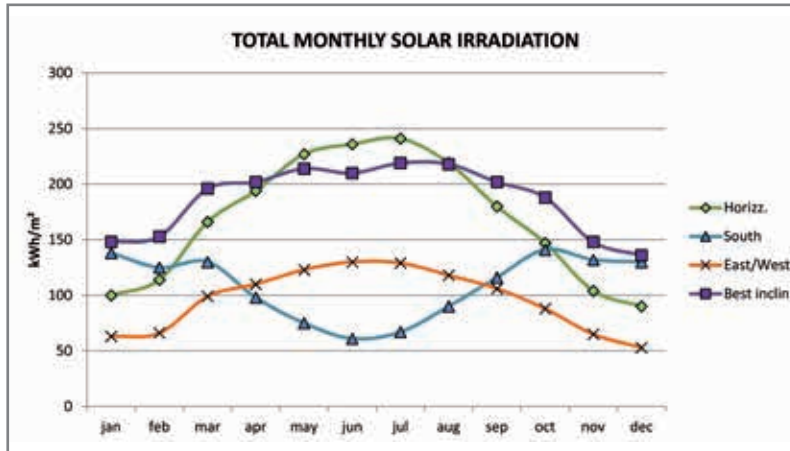


Fig 4 Global solar radiation by different orientation and inclination

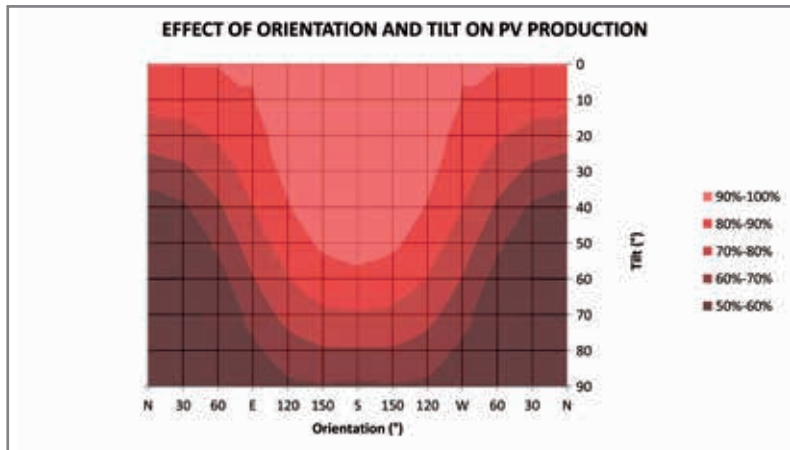


Fig 5 Percentage of output reduction by orientation and inclination

Lebanon

In the following the data regarding solar irradiation in Lebanon are given.

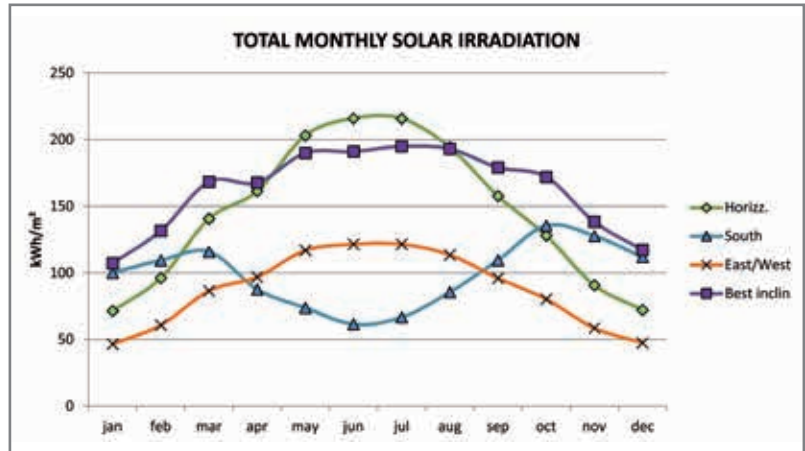


Fig 6 Global solar radiation by different orientation and inclination

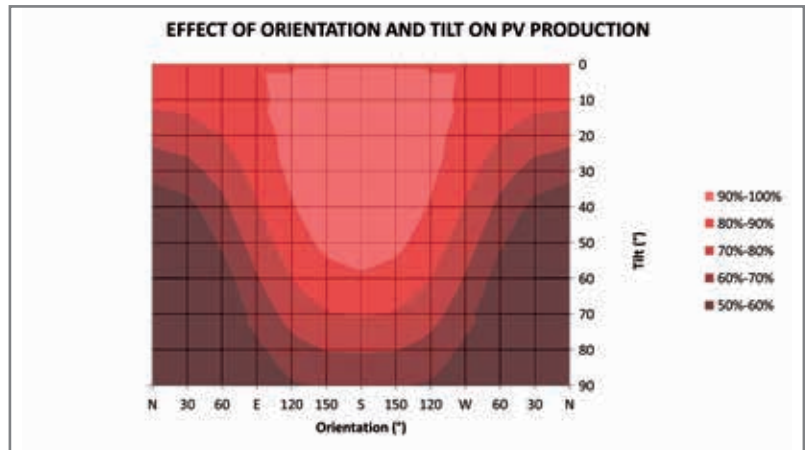


Fig 7 Percentage of output reduction by orientation and inclination

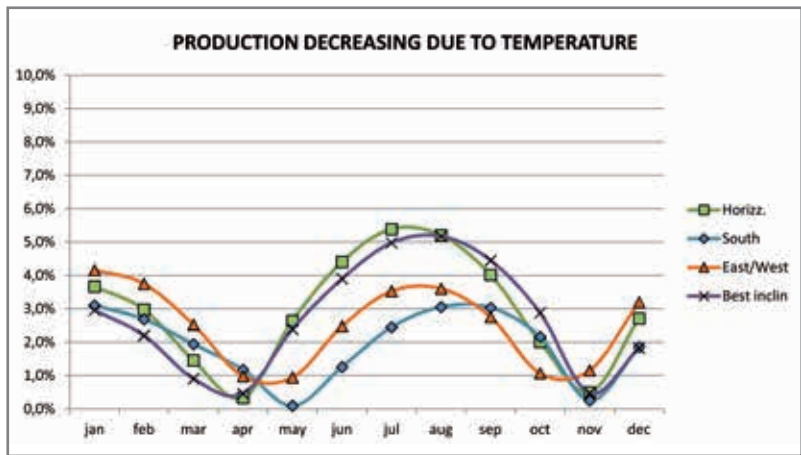
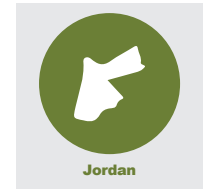


Fig 8 Percentage of output reduction due to temperature by orientation and inclination

Aqaba Region - Jordan

As illustrated in Figure 9, the total annual irradiation in Aqaba can reach up to 2160 kWh/m² when the PV system is tilted at optimal inclination angle. The maximum monthly irradiation per square meter (235 kWh/m²) occurs in June with a horizontal system installation.



The best inclination tilt angle gives the steadiest radiation for the whole year. The lowest irradiation levels occur when PV modules are installed to the true south, east or west.

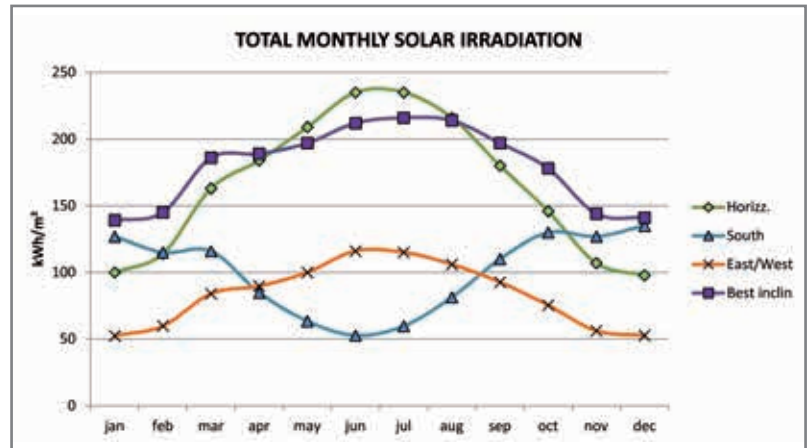


Fig 9 Global solar radiation by different orientation and inclination

In order to track the effect of orientation and tilt on PV production in Figure 10, it is important to know that the mean region latitude for Aqaba city is 29.531°.

Figure 11 shows the decrease or increase in the production of PV systems due to temperature variations.

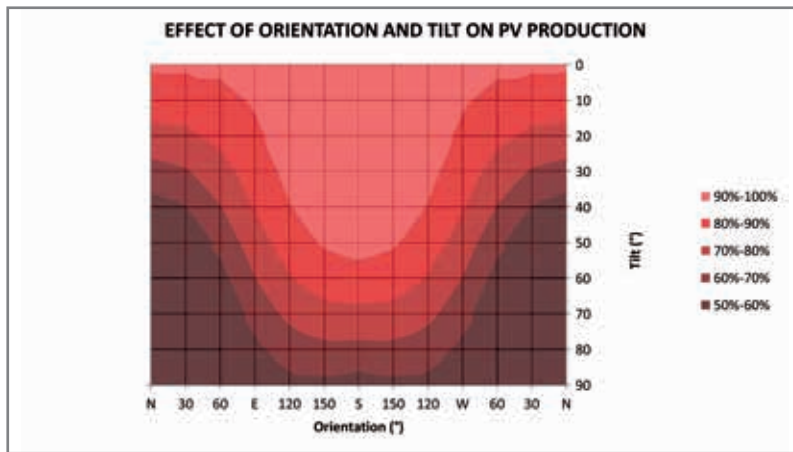


Fig 10 Percentage of reduction of solar radiation by different orientations and tilt angle

In Aqaba, the photovoltaic cell temperature (as calculated by the aforementioned formula) is closest to 25°C (STC conditions) during the winter months (December, January and February).

Some cases were encountered where the efficiency of the solar cell reached a value beyond its rating when the cell temperature was below 25°C (Irwanto, 2014).

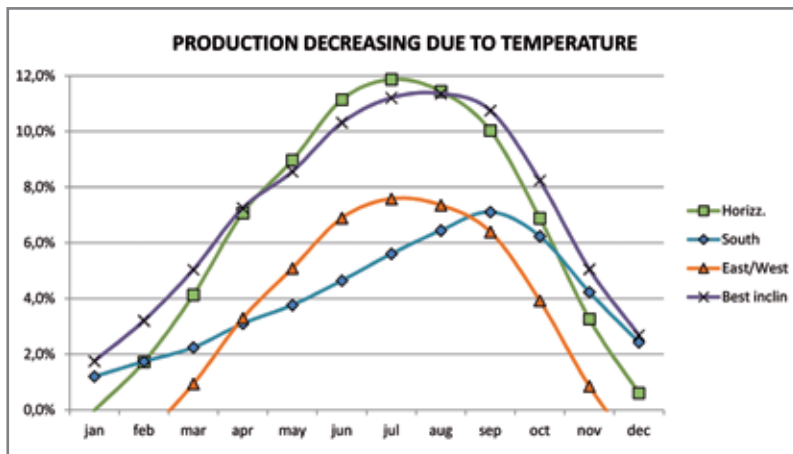


Fig 11 Percentage of reduction of PV production due to cell temperature

Tunisi Region - Tunisia

Tunis region is located roughly between latitudes 36,5° and 37° North, PV panels facing South and with a tilt angle of approximately 30° are the best design in terms of annual electricity production. During winter higher inclination would lead to slightly better production.



However, being that around 70% of annual energy is produced during sun shining period (March to October), then a tilt angle close to place latitude is advisable to maximize annual energy yield. In the Figure 12 the differences on monthly solar radiation by different orientation and angles in Tunis region are shown.

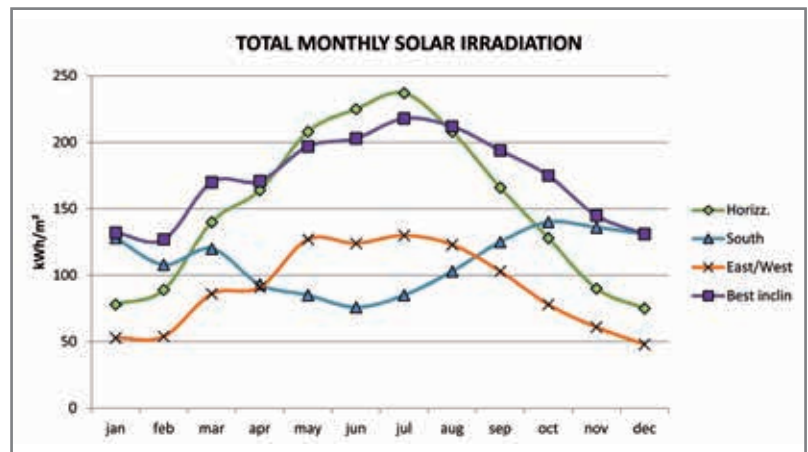


Fig 12 Monthly solar radiation by different orientation and angles

The following graph (Fig. 13) depicts the percentage of reduction of solar radiation by different orientations and tilt angle from the optimum. As it can be seen from the figure, solar panels installation can be flexible in both, inclination and tilt angle without reducing dramatically the plant performance.

It is advisable to reduce tilt angle for those PV generators not facing the best orientation (South).

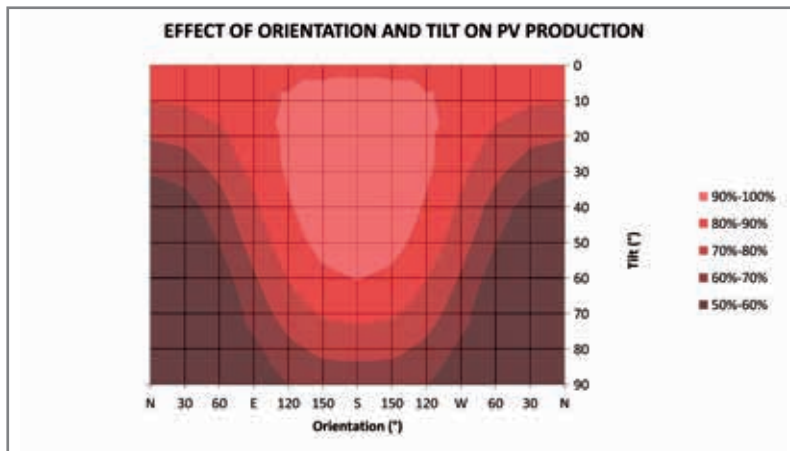


Fig 13 Percentage of reduction of solar radiation by different orientations and tilt angle

Sardinia - Italy

In the following the data regarding solar irradiation in Sardinia are given.

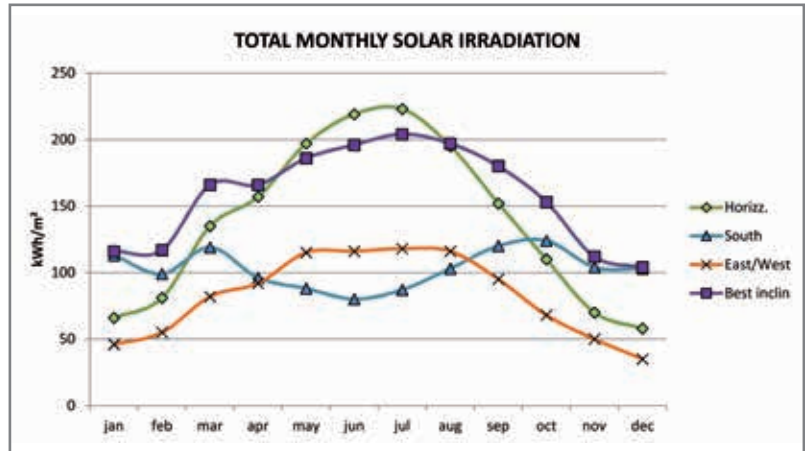


Fig 14 Global solar radiation by different orientation and inclination

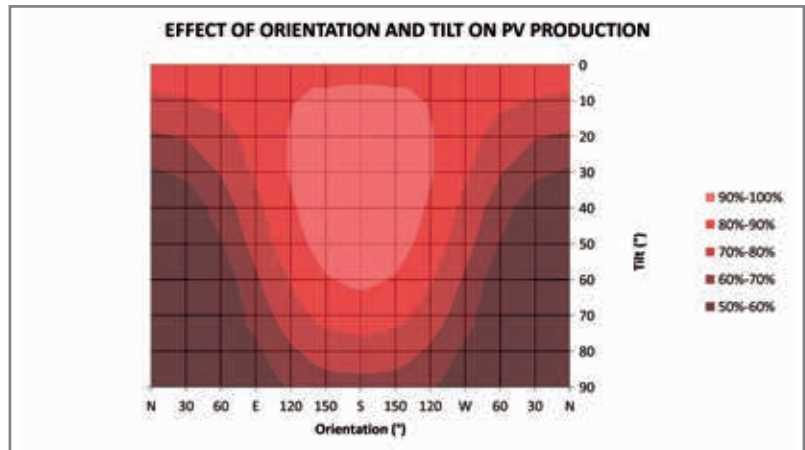


Fig 15 Percentage of output reduction by orientation and inclination

5.3 Rough sizing of a BIPV plant

The main parameters on which is based the calculation of a PV system are the conversion efficiency under standard conditions (η_{stc}) and the kilowatt peak (kW_p). The first is defined as the efficiency of a photovoltaic module that produces electric current in standard conditions, which are:

- Incident solar irradiance (G) on the module equal to 1000 W/m^2 ;
- Air temperature equal to 25°C ;
- Sunlight spectrum equivalent to 1,5 AM (Air Mass).

Test condition are generally recreated in laboratory and the electric power of a given PV module is then measured.

The efficiency η_{stc} is given by (3):

$$\eta_{stc} = \frac{P_{max}}{G \cdot A_{mod}} \quad (3)$$

where:

- P_{max} is electric power of the module (W);
- G is the irradiance incident on the module (1000 W/m^2)
- A_{mod} is the whole area of the module (m^2).

The kW_p is defined as the amount of panels needed to produce 1 kW power under standard conditions (it is not a unit of energy or power). To quantify the kW_p it is necessary to determine its surface, i.e. the surface of the panels needed to produce 1 kW of electric power in standard conditions.

According to (1):

$$A_{kWp} = \frac{P_{max}}{G \cdot \eta_{stc}} \quad (4)$$

For 1 kW_p P_{max} is equal to 1000 W, while under standard conditions G is equal to 1000 W/m^2 , thus (4) can be written:

$$[m^2] = \frac{1}{\eta_{stc}} \quad (5)$$

In (5) units are not respected. It just means that the area in m^2 of 1 kW_p of panels is equal to the inverse ratio of the standard condition efficiency. It is evident that using more performing modules the surface required to have a given electrical power will be less.

For example if $\eta_{stc}=10\%$; $A_{kWp}=10 m^2$
 $\eta_{stc}=12,5\%$; $A_{kWp}=8 m^2$
 $\eta_{stc}=5\%$; $A_{kWp}=20 m^2$

Now it is possible to estimate the production of 1 kW_p .

The electricity produced is dependent on the solar irradiation incident on the panels, thus on the geographical location.

For the city of Cagliari, for a surface oriented south with a tilt equal to 30° the annual irradiation is $\approx 1800 kWh/m^2$.

Integrating (1) over the time, it can be written:

$$E_{DC} = I \cdot A_{kWp} \cdot \eta_{stc} \quad (6)$$

Where:

- E_{DC} is the direct electric current produced in one year by 1 kW_p ;
- I is the average annual irradiation (kWh/m^2)
- A_{kWp} is the surface of 1 kW_p ; (m^2)
- η_{stc} is the efficiency under standard conditions.

According to (5), (6) can be written:

$$E_{DC} [kWh] = I \left[\frac{kWh}{m^2} \right] \quad (7)$$

Again units are not respected, but numerically the annual production of direct current by 1 kW_p is equal to the annual irradiation on 1 m^2 of PV plant.

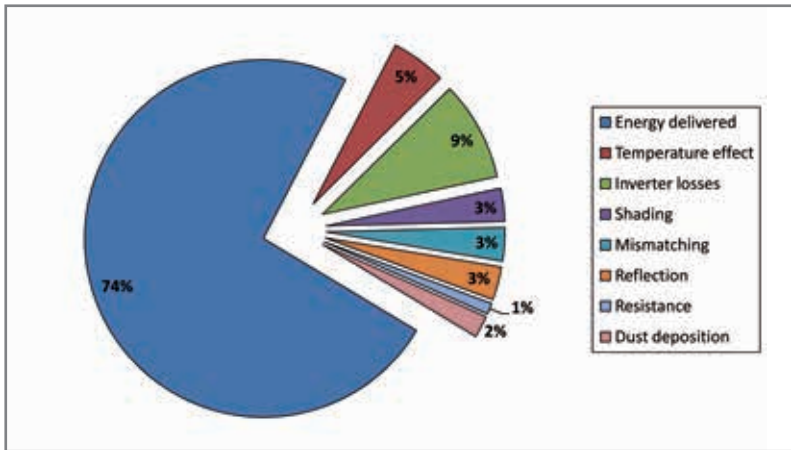


Fig 16 Average BOS efficiency for a PV system.

In Cagliari 1 kWp produces 1800 kWh/y, no matter which kind of panels is installed. This production however is just theoretical. Firstly panels very seldom work under standard conditions and secondly electricity needs a DC/AC conversion to be directly used by building appliances.

Thus a second efficiency called BOS (Balance of System) is introduced. It takes into account all the losses that are not considered in standard conditions. On average all the factors that contribute to the BOS are listed in fig. 16.

It is important to point out that for a BIPV the BOS can be reduced strongly if installation is not correct. For example if the panel cannot dissipate overheating by the ventilation of the bottom face, the losses for temperature effect can be much higher than 5%.

The energy produced by the whole system and delivered to the building grid is:

$$E_{AC} = E_{DC} \cdot \eta_{BOS} \quad (8)$$

where E_{AC} is the inverter output energy (alternate electrical current) if the system is grid connected.

Now it is possible to simulate different sizing scenarios starting from different inputs.

5.3.1 Sizing by destination of use (residential, commercial, office, schools...)

Generally, using as much of the energy produced by PVs in the building makes sense.

The amount of PV energy usable on site is related to the size of the array and the magnitude and pattern of the demand. A wide range of building types from offices to hotels to houses can use PVs. Office blocks have good PV potential because their electricity demand is significant year-round (including the summer) and because demand is highest between 9am and 5pm. Thus, the match between demand and PV supply is good. Houses, on the other hand, are more challenging because the times of required demand are more intermittent and highly dependable upon the way in which occupants use the house. Grid connected systems work best with dwellings as the grid in effect acts as a storage device. Commercial and industrial buildings with large roof available areas also offer significant scope for PVs. Energy consumption varies with both type and the shape of the building, so a design should be carried out at an early stage of the design process.

As an example, in Sardinia an average family uses 3000 kWh of electricity per year. If all the need is to be covered by a PV plant,

$$E_{CA}=3000 \text{ kWh}$$

$$E_{CC}=E_{CA}/\eta_{BOS}=3000/0,74=4054 \text{ kWh}$$

Since 1 kW_p produces in one year the same amount of solar energy incident on 1 m² of panels, the number of kW_p necessary to cover the need will be:

$$N_{kWp}=4054/1800=2,25 \text{ kW}_p$$

If we consider a cost per kW_p equal to 2.500 €, the investment for the plant will be 5.625 €.

Please note that data on solar radiation refers to optimal orientation and tilt, but not necessary to the best integration option.

5.3.2 Sizing by building element

To ensure safety, there are measures and steps that need to be taken or considered when installing a solar PV system onto a new or an existing building. For new building developments, the design of the structure must take into consideration the load of the solar PV system installation, just like any other equipment mounted onto a building structure.

For existing buildings, a professional structural engineer may be required to carry out an inspection of the roof structure, and do a calculation on the structural loads.

Given a certain location, solar PV systems are exposed to the threat of lightning strikes. As lightning can cause damage to the PV modules and inverters, extra care must be taken to ensure that proper lightning protection is provided for the solar PV system and the entire structure. The inverters should be protected by appropriately rated surge arrestors on the DC side. It is good practice to also install surge arrestors on the AC side. Structures and PV module frames must be properly grounded.

BIPV system can be strongly dependent on the building surfaces available for the installation. In that case can be useful to estimate the size of the plant.

Let us assume that the roof has a south facing slope with a tilt of 30° and a surface of 15 m^2 .

It is necessary to choose a specific technology since the η_{stc} must be known. Assuming a $\eta_{stc}=10\%$ the $A_{kWp}=1/0.1=10 \text{ m}^2$. It means that each kW_p takes up 10 m^2 of the roof slope.

The maximum NkW_p that can be installed is $15/10=1,5$.

The total annual production will be:

$$ECA=N_{kWp} \cdot I \cdot \eta_{BOS}=1,5 \cdot 1800 \cdot 0,74=1.998 \text{ kWh}$$

If we consider a cost per kW_p equal to 2.500 €, the investment for the plant will be 3.750 €.

6. Electrical connections and components

Once PV system were divided into two main categories:

- Grid connected
- Stand alone

Grid connected PV systems always have a connection to the public electricity grid via a suitable inverter because a photovoltaic panel or array (multiple PV panels) only delivers DC power. As well as the solar panels, the additional components that make up a grid connected PV system compared to a stand alone PV system are:

- Inverter: the inverter is the most important part of any grid connected system. The inverter extracts as much DC (direct current) electricity as possible from the PV array and converts it into clean AC (alternating current) electricity at the right voltage and frequency for feeding into the grid or for supplying domestic loads. It is important to choose the best quality inverter possible for the budget allowed. The main considerations in grid connected inverter choice are: power (maximum high and low voltage power the inverter can handle) and efficiency (how efficiently does the inverter convert solar power to AC power). Designers should choose inverters that comply with national standards and regulations.
- Electricity meter: the electricity meter also called a Kilowatt hour (kWh) meter is used to record the flow of electricity to and from the grid. Twin kWh meters can be used, one to indicate the electrical energy being consumed and the other to record the solar electricity being sent to the grid. A single bidirectional kWh meter can also be used to indicate the net amount of electricity taken from the grid.
- The system should be equipped by safety components that comply national standards and regulations.
- The electricity grid: finally the electricity grid itself to connect to, because without the utility grid it is not a grid connected PV system and will not generate electricity.

A grid connected system without batteries is the simplest and cheapest solar power setup available, and by not having to charge and maintain

batteries they are also more efficient. The building becomes less dependent on the electric utility companies and fulfils part of its own energy need. The balance between solar energy production and household electricity consumption is still obtained with the help of the utility grid. An overproduction in the day is sent into the grid and a demand in the evening is drawn from the electricity network. The grid is used as a virtual storage.

Stand alone systems instead have no external connection, but provide (sometimes together with other small electricity generators) the whole energy need. In that case, since the overproduction during the day cannot be lost, the system is implemented by an electrical storage, generally a battery bank.

Nowadays, however, this classification is obsolete and the future PV technologies will always foresee local storage, even if grid connected.

Local storage solutions pave the way for many new applications. Examples are:

- over voltage of the line due to too many injecting inverters on the grid is omitted by storage;
- periods of power-line black-out can be bridged provided that the building is allowed to work in stand alone mode.

Other new business cases can be identified. Buildings that store their produced energy may allow their electricity provider to switch them off during periods of peak demand. In return they may receive a discount or a payment. Moreover, the new realm of possibilities is so called smart grid applications. A building can interactively work with the grid and trade with the power markets. Peak reduction and demand response can be established more thoroughly than without storage. A building can even start to trade on energy markets on arbitrary moments.

The necessity of local storage is also evident in those countries where electricity grid has no shortage or outage problems (Italy and Spain among FOsterinMED partners). The reduction of incentives in the last few years made less convenient the exchange of electricity with the grid, since the overproduction is not subsidized anymore.

So, even in those cases a next step could be to store the produced electric energy during the day for delayed consumption in the night or the day after.

Classically the storage for PV panels was mostly designed for stand-alone applications. This meant that an amount of energy should have been stored to fill at least the production gap of several days of very clouded weather.

Future applications will deal with small-scale storage to accumulate a part of the solar power of one day for postponed consumption within the day or the next days. If the building is grid-connected a storage system should not necessarily cope with a long period of low solar energy production, as the grid is available as a back-up. Hence the sizing criteria can be different from completely autonomous systems.

Incorporating storage into a grid connected system requires more components.

A PV system with storage is basically the same as for the previous grid connected PV system with the addition of the batteries (or other technologies) and charge controller. The charge controller, determines whether the power generated by the solar panels is needed for home use, to run low voltage equipment and lighting or whether it will charge the deep-cycle backup batteries to be used later on. The DC current leaving the controller passes through the DC to AC inverter, transforming it into electricity usable by general building appliances. Any surplus electricity not being consumed or used by the building can be sent to the electricity companies' power grid. It should be better to run DC rated lighting and appliances first directly off your solar system before the current is converted to AC from the inverter. This will gain the most efficiency.

06

Good practices





The good practices listed below have been chosen after a vast choice of buildings spread throughout the world. They include museums, exhibitions and commercial centers, hospitals, urban design installations, private residential building. They are not supposed to be considered the best aesthetical or functional building solution, but they are expected to be looked at as examples of use of PV systems in different geographical, cultural, climatic contexts.

In these examples PV have been used as roofing, façade cladding, shading, as protection and art piece, transparent or matt, proofing that this technology is far ready to be employed in the most versatile and adaptable way.

SHEIK ZAYAD LEARNING CENTER AT AL AÏN ZOO

Location: Al Aïn - Abu Dhabi

Use: Public (Learning centre)

Project: iC consulenten Ziviltechniker GesmbH

Power: 150 kwp



Fig 1 Desert learning center, Al Aïn - Abu Dhabi



Fig 2 Desert learning center construction site, Al Aïn - Abu Dhabi

Committed to the most demanding sustainability requirements set by Abu Dhabi Urban Planning Council (UPC), the SHEIK ZAYAD LEARNING CENTRE is the first government sustainable building to attain the highest possible rating for sustainability.

The project's design process brought together an interdisciplinary team of building and landscape architects, structural, electrical and mechanical engineers, museum interpretive designers, and sustainability consultants to work collaboratively and iteratively, in pursuit of high performance improvements. This process developed into a single integrated, highly sustainable solution.

The building is practically operable on an 'energy autarchic basis' thanks to the application and combination of the best available domestic lighting and ventilation techniques. Some of them include:

- Building orientation and massing: The position and perforated form of the internal courtyard in the building promotes air movement through and around the courtyard.
- Natural earth as insulation: A substantial portion of the building is subterranean, lowering the difference between external and internal temperatures
- Day lighting: The building is oriented to maximize daylight inside the building. Recessed openings and indirect skylights provide high quality natural light while avoiding excessive solar heat gain. Small aperture windows allow natural light while limiting heat transmission
- Shading: Large cantilevered overhang provide shade over the main entrance of the building. Retractable fabric shading devices will be used to cover the outdoor spaces and courtyard during summer.
- Photovoltaic power: Photovoltaic collectors cover the entire roof of the building generating 150 kW. In this way the building produces almost 95 percent of the required primary power.

Meier Hospital Photovoltaic Plant, Florence

Location: Florence, Italy

Use: Hospital

Architect: CSPA Firenze, arch. Paolo Felli

Cooperation: arch. Antonella Trombadore, arch. Giuseppina Alcamo,
arch. Paola Gallo, arch. Lucia Ceccherini, ing. Silvia Murgia

Energy consultant: MSA

Power: 30 kwp



Fig 3 Meier Hospital, Florence, Italy

The Meyer's photovoltaic greenhouse is a structure with a southern exposition and unobstructed solar access in order to maximize the collection of winter sunshine; it is not only a particular type of structure but also, and more importantly, a particular kind of space. The design objective not only considered energy and environmental aspects but also social impact: the primary objective is to create a pleasant and "socializing" space which can be used for semi-outdoor activities through most of the year without any extra energy space, a social space well

integrated into the adjacent green park. PV installation integrated into building greenhouse facades allows the possibility of combining energy production with other functions of the building envelope, such as shading, weather shielding and heat production. Cost savings through these combined functions can be substantial, e.g. in expensive facade systems where cladding costs may equal the costs of the PV modules. Additionally, no high-value land is required and no separate support structure is necessary. Electricity is generated at the point of use. This avoids transmission and distribution losses and reduces the utility company's capital and maintenance costs. The Photovoltaic system is 30 kWp and realised with glass/glass PV modules.

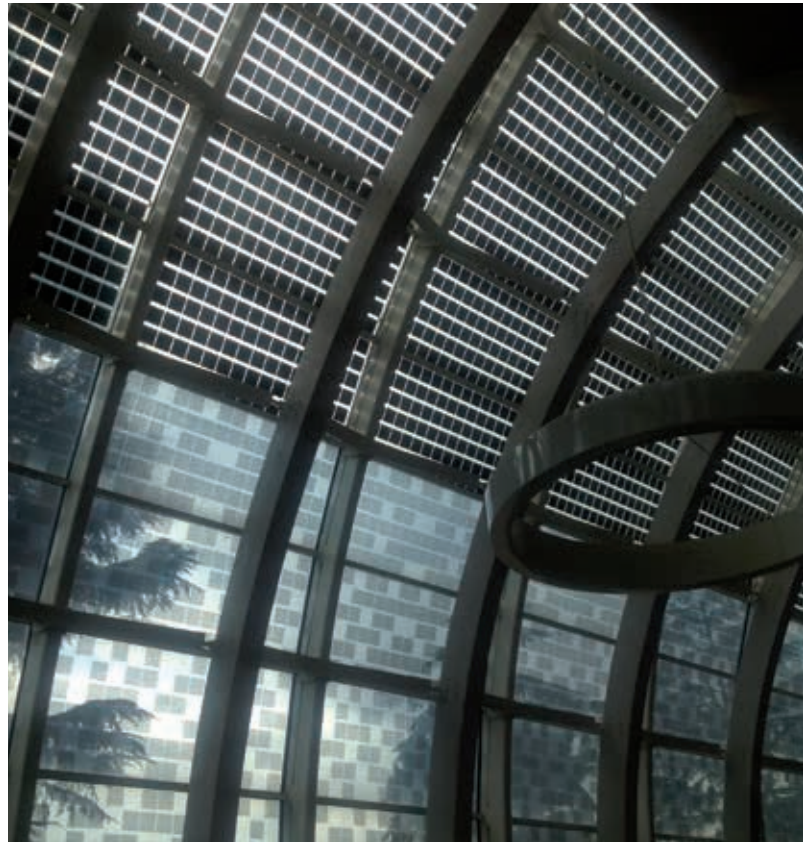


Fig 4 Meier Hospital, Florence, Italy

Cite du Design in St. Etienne

Location: Saint Etienne, France

Use: Multi functional

Architect: LIN Architects - Berlin

Power: 25 kwp

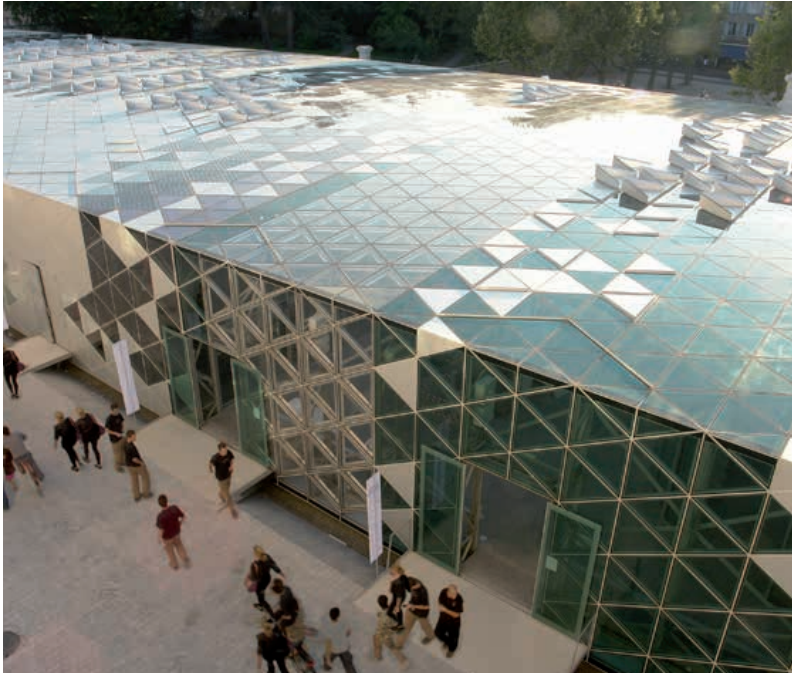


Fig 5 Cité du design, opening

Designed in 2009 by Berlin and Paris based LIN, the Cité du Design hosts auditoriums, meeting rooms, exhibition space, a media library, and indoor gardens with an observation tower located alongside the long hall. A latticed 3D structure forms the walls and roof of the complex, and the interior of the hall is left open without any supports or beams to get in the way. The center is very energy efficient and utilizes a heat exchange and recovery system to reduce energy used for heating. Pre-conditioned air from the internal gardens, which are not heated, is drawn into the system to heat the nearby rooms.

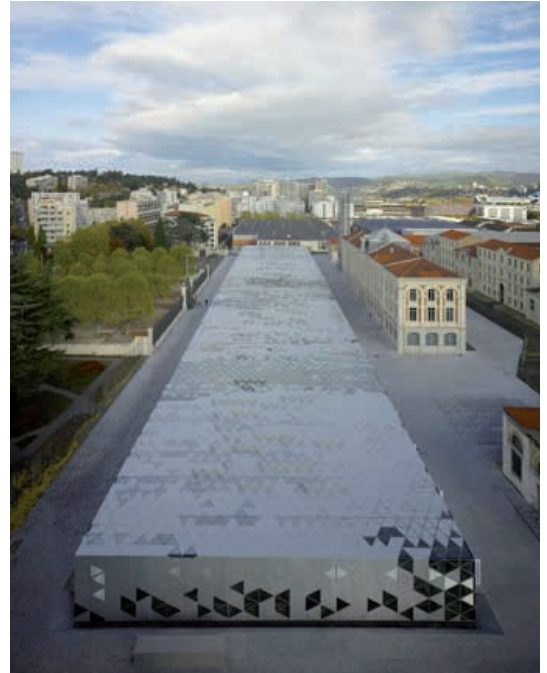


Fig 6 Cite du Design, aerial view of the platine

The Platine envelope, consisting of 14,000 equilateral triangles measuring 1,2 m per side is a graduated and reactive skin: modulation between opaque and clear, insulated or interclimatic, open or closed, reflects and accompanies the various cycles and interactions of the Cité du Design. The choice of glazing type allows a distribution of natural light depending on the use of the premises.



Fig 7 Cité du design, Saint Etienne

Thermal qualities of the panels permit the climatic quality of the envelope to be modulated according to unplanned criteria of the premises. The possibility of integrating solar panels (photovoltaic and experimental) into the skin of the Platine allows solar energy production as well as development and testing of innovative solar energy materials. The skin reacts continuously to changes in climate. It may also be given new functions. In the longer term, the panels may be replaced or modified to be adapted to changing needs or to allow for areas of experimentation.

El Centre del Món

Location: Perpignan, France

Use: Multifunctional centre (Train and bus station, Shopping, offices, hotels)

Project: L35 Arquitectos

Power: 232 kwp

The extended area of the new TGV station in Perpignan which includes the multifunctional complex (TGV station, a bus station, a shopping center, offices and two hotels), is the element on which pivots the municipal urban operation aiming to revitalize the Saint Assisclé quarter and convert the new station into an intermodal center of urban development and new economic engine of the city.



Fig 8 El centre del Món, Perpignan, France

The project is structured along an axis parallel to the track layout, creating a public path between two rows of buildings, one right beside the tracks and another facing the city Boulevard.

The façades are treated with a ventilated outer skin of glass colour changing from dark blue to dark red to orange, green and blue various yellows, creating a dynamic and diverse effect along the 400 m building length. Here semi transparent photovoltaic modules, mounted on a long metallic undulated stripe, are used to cover the passage in between the two long buildings, allowing light to illuminate the atrium and at the same time protecting from the rain.

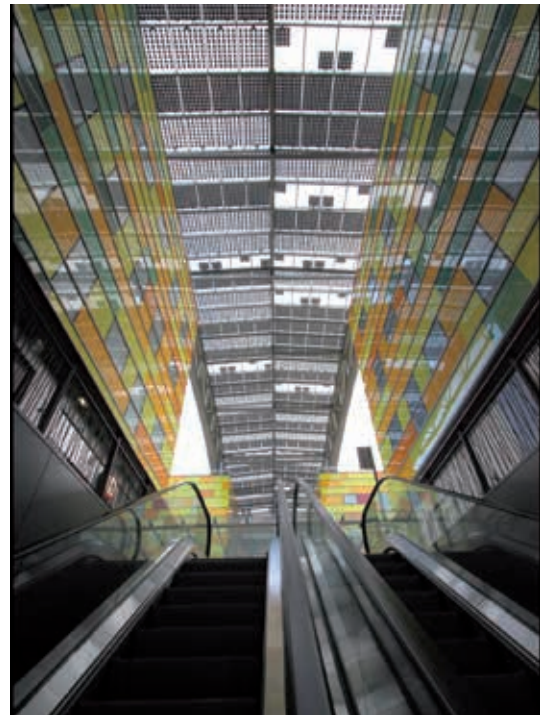


Fig 9, 10 El centre del Món, Perpignan, France

House of Music

Location: Aalborg (Danimarca)

Use: concert hall

Project: COOP HIMMELB(L)AU

Designed by Austrian firm Coop Himmelb(l)au, this multifunctional center is a marvel of Solar passive design and features a south-facing facade covered with thin-film photovoltaic that helps to reduce its energy use. With a 1300 seat concert hall, auditoriums, public courtyards and sustainable design features, Denmark has a wonderful new addition to its cultural scene. In order to ensure optimum utilization between shading and daylight need, no rectangular, but triangular modules were designed and assembled with just triangular perforated metal panels in an unfolded position on the façade. The 2,3x2,3 m large modules are covered with semi-transparent cells, that give especially in the night an interesting in-



Fig 11 House of music, Aalborg, Denmark

and out view results. Moreover, the glass elements set diagonally act as a kind of wind breaker, and in turn permits to open windows even in high buildings. Besides all these functions should be mentioned that the façade provides about 70 kWh per m² and year.



Fig 12, 13, 14 House of music, Aalborg, Denmark

Museu de la Ciència i de la Tècnica de Catalunya (MNACTEC)

Location: Terrassa, Catalunya

Use: Museum

Contractors:

Museu Nacional de la Ciència i de la Tècnica de Catalunya, ES

Laboratoire Analyse et Architecture des Systèmes du CNRS, FR

Teulades i Façanes Multifuncionals SA (TFM), ES

BP Solarex, UK

Power: 38,7 kwp

The museum has chosen a photovoltaic coloured façade as a technological and architectural covering for the dividing wall of the apartment building adjacent to the centre. The wall has been covered with a metallic structure on which were installed 527 photovoltaic modules connected



Fig 15 Museu de la Ciència i de la Tècnica de Catalunya (mNACTEC), Terrassa

to the general grid. The coloured photovoltaic façade is mounted on a structure that reminds of a curtain-wall, so that it acts as a system that produces electricity and at the same time it also avoids that the dividing wall cools too rapidly down during the winter and overheats in the summer. Modules are of two types: standard high-performance mono-crystalline blue cells and translucent, magenta and golden mono-crystalline which allow over 10% of solar radiation.

Despite the fact that the blue modules have a sunlight conversion efficiency into electricity higher than the other two colours, it was chosen to prioritizing the aesthetic criterion ahead of some functionality, as this is a façade located in a place situated in a very busy and visible part on Rambla d'Egara, one of the main streets of Terrassa. The PV installation has a power of 39.7 kWp and occupies an area of 300 m². It produces annually about 40,000 kWh which is covering the 15% of the electrical demand of the museum, and has become an emblematic structure for both the museum and the same city of Terrassa.



Fig 16 Museu de la Ciència i de la Tècnica de Catalunya (mNACTEC), Terrassa

Renzo Piano's Pavillon at Kimbell Art Museum

Location: Fort Worth, Texas

Use: Museum

Project: Renzo Piano Building Workshop and Arup

PV CONTRACTOR: GIG Fassaden, USA

Modules: 2.403 VSG 2/4

Dimensions 2.230 x 180 mm

Power: 120 kWp

Piano's low-slung, colonnaded pavilion with overhanging eaves graciously acknowledges Kahn's museum building by way of its kindred height, emphasis on natural light, and use of concrete as a primary material. The pavilion is made up of two sections connected by a glass passageway. The front, or easternmost, section conveys an impression of weightlessness: a glass roof system seems to float high above wooden beams and concrete posts. Sleek, square concrete columns flank the central, recessed glass entrance and wrap around three sides of the building.



Fig 17 New Pavillon at Kimbell Museum, USA. Roof.

The tripartite facade articulates the interior, with a spacious entrance lobby and large galleries to the north and south.

Tucked under a green roof, the Piano Pavilion's western section contains a gallery for light-sensitive works of art, three education studios, a large library with reading areas, and an auditorium with superior acoustics for music. The latter, located below ground level, is a design centerpiece: its raked seating faces the stage and the dramatic backdrop of a light well animated by shifting patterns of natural light.

The roof is a single layer that performs an array of functions. Sitting just above the glass is a photovoltaic louver system. Its first job is to control the amount of light entering into the space, and it can be either fully closed or open to any position between zero and 45 degrees. In the case of serious weather, such as hail, they rotate and fold over to protect the glass roof structure. The PV cells within the louvers generate enough power to meet about 70 percent of the lighting energy needs for the building, Davies says. The louvers also keep sun off the glass, and each module is individually controlled by a dedicated louver control system.



Fig 18, 19 New Pavillon at Kimbell Museum, USA. Roof.

Klimahaus Bremerhaven

Location: Bremerhaven, Germany

Use: Edutainment Centre

Project: Klumpp Architekten, Bremen, Transsolar Energietechnik GmbH

Modules

143 VSG-ISO 66,2(14)66,2 with Digiprint

dimensions 1.180 x 1.700 mm

Power 35,7 kWp

The architectural design for the Edutainment Centre is a transparent, freestanding glass envelope wrapping around the internal concrete structure. The house-in-a-house concept is used for the approx. 15,000 m² of exhibition area. In the 'travel' zone ('Reise'), the visitor will gain realistic experience of important climatic regions of the world. To this end, approx. 5,000 m² of the exhibition area are conditioned to reproduce extreme conditions ranging from arctic to moderate and subtropical humid to extremely dry desert climates.



Fig 20 Klimahaus Bremerhaven, Germany

A climatic concept for the other exhibition areas such as 'elements', 'perspective' and the foyer is compatible with the requirements of the exhibition and exhibit architecture and the varying visitor numbers. Apart from facade-incorporated photovoltaic elements, for these exhibition areas only natural energy sources are used for cooling and ventilating. The chosen climate and energy concepts fulfil the aims of the project, which are to promote responsible behaviour towards the environment in addition to providing information.



Fig 21, 22 Klimahaus Bremerhaven, Germany

Stadtwerke Konstanz Energy Cube

Location: Constance, Germany

Use: Customer service centre

Project: Stadtwerke Konstanz

Project Façade / roof

Modules 17 VSG-ISO

max. dimensions 2.988 x 3.911 mm

Power 24,54 kWp

The Energy Cube has a combined surface area of circa 800m² spread across its floors. The structure stands upon 47 piles, themselves embedded into the earth down to a depth of 18 metres. The façade is transparent and consists of 80 large glass elements with a combined surface area of around 1000m². Individual areas of the façade can be illuminated in the corporate colours of the Stadtwerke. As a result of planning, the new customer centre is particularly energy efficient and utilises renewable energy sources.



Fig 23 Stadtwerke Konstanz Energy Cube, Germany

The new building, over its useful life, will generate more energy than it consumes itself. The energy from the sun and the earth will be used as electricity, for warmth and for cooling. Reversal pumping obtains, according to requirements, either warmth or cooling from the ground. Upon the roof and the south façade a photovoltaic installation generates electricity. Also amazing is the benchmark data from the façade integrated photovoltaic installation. When the horizontal edge length is divided by five and in the case of the verticals, by four, this results in the incredible maximum dimensions of 2,988 x 3,911 per panel. Also high is the corresponding power from each module, with a maximum of 1,246 kWp – an absolute photovoltaic record. Not only the power, but also the weight surpasses all superlatives. In triply insulated glass with glass packets up to 64mm, this results in the largest module being a phenomenal 1,014kg. The combined installation amounts to 23,2 kWp and has in addition, because of the use of semi-transparent cells, a transparency of circa 22%. In only a few weeks will the visitors to the customer service be able to admire the architecture as well as the energy aspect of a unique flagship façade.



Fig 24 Stadtwerke Konstanz Energy Cube, Germany

House on the Hillside in Passail (Austria)

Location: Passail, Austria

Use: House

Project: Architectural firm Kaltenegger, Passail, Austria

PV CONTRACTOR: Möstl plant, Passail, Austria

Modules: 20 VSG 8/10

Dimensions: 1.555 x 2.000 mm

Power: 4,7 kWp

The unusual residential building is located on the edge of a slope near Passail, in Austria. Its base plate rests, among other things, on six columns, which give the building an additional floating effect.

The location, with a wide view of the valley and a large surface area, lead to the definition of the spatial concept. Accordingly, the architect endowed with a wraparound terrace and opened it using a large glass front facing south-west into the valley.



Fig 25 House on the Hillside Passail, Austria

The space program in addition to a spacious living / dining area includes also two bedrooms, the necessary sanitary and technical rooms and two covered parking spaces.

Although the building has a very large surface exposed to open outside air, it almost reaches passive house standard.

The parapet of the wraparound terrace on the side of the valley is not only for safety, it is also used to generate electricity: photovoltaic elements (total of 19 laminated glass modules) produce each 245 Wp, resulting in an installed plant capacity of 4,65 kWp. For mounting the modules the stainless steel point holders were sunk in the rear glass and are not visible from the front. The junction boxes and cabling are hidden in the terrace floor.

B.O.C. - Bonnheshof Office Centre

Location: Düsseldorf, Germany

Use: Office

Project: RKW Rhode Kellermann Wawrowski Architecture

+ Urban Design, Düsseldorf

Photovoltaics: bauwerk integrated photovoltaic

BIPV Schüco monocrystalline

Modules: 114 VSG 6/6 dark grey

Dimensions: 1.300 x 3.300 mm

Power: 63,3 kWp



Fig 26, 27 B.O.C. - Bonnheshof Office Centre

The modern building complex Bonneshof Office Center - BOC in Düsseldorf expands the existing building, the Tersteegen Office Center - TOC, to approximately 12000 m² of new floor space and creates a new two-storey glass lobby. The five-storey office building with a penthouse level and underground parking was implemented according to plans by Quantum Immobilien AG as the general contractor and completed in early 2014. The facade concept is based on a special construction of a double facade with different curtain panels in the outer layer. The main components of the facade are based on special versions of the Schüco AWS 75 aluminium system with high thermal insulation and block system profiles. The U-value of the total facade is 1,3 W/m²K, whereas the glass' one is 1,0 W/m²K. The main building is characterized by the alternation of glass facade and curtain panels. The basic module has a height of 3,5 m and 2,7 m width, consisting of window elements with opening casements in the inner, thermally active layer and a photovoltaic panel in the outer layer. Within the framework of special design, an additional sun protection in the form of external venetian blinds is integrated.

The structure of the solar screen panels or PV modules made of laminated safety glass consists of two semi-tempered glass panes 6 mm thick with different inner layers. In the glasses used as solar protection the rear side of the outer layer sheet was printed digitally in accordance with the architect's design with a white pattern. The photovoltaic glasses are made of photovoltaic cells embedded between two glazed layers. Crucial for the visual impression is the use of "Dark Grey" colour in the back glass. The overall PV area is about 500 m². Each module consists of 133 mono-crystalline with a capacity of 555 Wp. The total capacity of the system in the vertical façade envelope is 63 kWp. The system was fully installed including cables and inverters. The active facades are each connected separately on its own inverter, in order to exclude mismatch power losses of the series connected photovoltaic modules due to different angles of incidence. The energy active building envelope is a characteristic design feature of the office building and contributes also significantly to the energy efficiency. A modular system of prefabricated elements made easier the mounting and wiring on the ground and led to an assembly time of just eight weeks. This architecturally expressive and technically efficient facade is a successful example of the use BIPV.

Greetings to the Sun

Location: Zadar, Croatia

Use: Monument

Project: Nikola Bašić

Modules: 328 VSG 6/12/12 walkable

Dimensions: max. 1.102 x 1.102 mm

Greetings to sun is located in the port of Zadar, on the western point of the Zadar peninsula, next to the Sea Organ. This is the place overlooking the city harbour, the islands and the famous Zadar's sunset. The monument symbolizes the Sun with the solar plates absorbing solar energy in daytime and transforming into unusual light effects during the night. It uses solar power to create a light show that displays at night. After sunset the lighting elements are activated, and following a particularly programmed scenario, they produce very impressive show of light.

The artistic installation consists of three hundred multi-layered glass plates, incorporated in the stone quay in the shape of a circle that measures 22 meters in diameter. People can walk on it. Below each glass pane there is a photovoltaic solar modules.



Fig 28 Sun monument Zadar, Croatia

There is also a grid of light points underneath the glass, consisting in fact of a dispersed display with over 10.000 tiny light bulbs. Each single bulb changes intensity and colour induced by a computer. In fact, this is an installation that could emanate light in all its possible sensations, send messages, form graphemes and write words.

In the future by entering the light circle a walker will induce a specific light reaction. One person will induce one reaction, the other person another, ten persons will induce ten cumulative effects.

The designer's intent was to rejoin in urban space the joy of playing, of meetings, of the possibility to get in touch with nature, the pleasure of recognizing certain important and dear places to which inhabitants like to return and to reinforce the sense of belonging to a town.



Fig 29, 30 Sun monument Zadar, Croatia



Fig 31 Sun monument Zadar, Croatia

Credits

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01 _ Introduction

Cover

“Projet BIPV - Gare TGV de Perpignan” by Issolsa. Licensed under CC BY-SA 3.0 via Wikimedia Commons

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02 _ Pv Module Types

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Fig 1

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Fig 2

Final installation and layout of Uni-Solar Ovonic's thin Film Flexible Solar PV panels, “Heckert GNU white” by Aurelio A. Heckert <aurium@gmail.com> - gnu.org. Licensed http://commons.wikimedia.org/wiki/File:Thin_Film_Flexible_Solar_PV_Ken_Fields_1.JPG#/media/File:Thin_Film_Flexible_Solar_PV_Ken_Fields_1.JPG

Fig 3a

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Fig 4

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Fig 6

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Fig 7a

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Fig 7b

Dawn solar panel by NASA/George Shelton May 21, 2007

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Fig 8

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Fig 9

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Fig 10

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Fig 11

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Fig 12

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Fig 13

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03 _ Pv Integration

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Fig 2

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http://upload.wikimedia.org/wikipedia/commons/d/d8/Thin_Film_Flexible_Solar_PV_Installation_2.JPG

Fig 3

Ministerio de Fomento, SML House Universidad CEU Cardenal Herrera de Valencia (España), Solar Decathlon Europe 2010
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Fig 4a

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Fig 4b

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Fig 5a

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Fig 5b

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Fig 5c

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Fig 6

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Fig 9

“Akademie Mont-Cenis view inside 1” von Arnold Paul - Eigenes Werk. Lizenziert unter CC BY-SA 2.5 über Wikimedia Commons
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Fig 10

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04 _ Improving social, institutional and building designers' outlook

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05 _ BIPV performance

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06 _ Good practices

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Fig 1-2

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Fig 3-4

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Fig 5

SCD-12-ESS-LIN-Cite du Design opening, 2009, photo: Jan Oliver Kunze
www.lin-a.com

www.lin-a.com/gallery/arms-manufacture-design-lin-project-orta-platine-saint-etienne/cite-du-design

Fig 6

SCD-22-ESS-LIN-aerial view of the platine, photo: Christain Richters
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Fig 7

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Fig 10

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Fig 12-13-14

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Fig 15

Museu de la Ciència i de la Tècnica de Catalunya. Photo by Enfo, licensed under CC BY-SA 3.0

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Fig 16

Photovoltaic wall near Barcelona, Spain. Photo by Chixoy, licensed under CC BY-SA 3.0
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Fig 17-18

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Bibliography

I. Hermansdorfer, C. Rub Solar Design- Photovoltaics: Old Buildings, Urban Space, Landscapes JOVIS Verlag, Berlin 2005

A. Basnet

Architectural Integration of Photovoltaic and Solar Thermal Collector Systems into buildings Master's Thesis in Sustainable Architecture Norwegian University of Science and Technology Faculty of Architecture and Fine Arts - Department of Architectural Design, History and Technology Trondheim, June 2012

Reijenga, TH and Kaan, HF.

PV in Architecture, in A. Luque, S. Hegedus Handbook of Photovoltaic Science and Engineering John Wiley & Sons Ltd, 2003

M. C. Munari Probst, C. Roecker

Architectural Integration and Design of Solar Thermal Systems EPFL Press, Lausanne 2011

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