EDG 68 MS • July 2011 (Edited 22.11.2018)
acumen.architecture.com.au/environment
Reviewed and approved for currency in November 2018

ISSN 1442-5017

Building-Integrated Photovoltaics (BIPV)

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Figure 1: Mont-Cenis Academy building, Herne, Germany. A 1MWp BIPV array
(Image: BSW-Solar)

ABSTRACT

This note deals with architectural issues associated with photovoltaic (PV) power systems integrated into building design. It follows on from EDG note TEC 4, 'Photovoltaic Cells – How They Work'.

New photovoltaic materials offer new design options: the challenge for designers is to combine technological and architectural considerations to produce integrated applications in buildings. This note details the opportunities presented by BIPV and gives an outline of key issues for the conceptual designer, including a value proposition for convincing prospective clients.

This note was originally published as DES 28 in August 1999. Its authors were Deo Prasad and Juliet Byrnes. It was reviewed by Deo Prasad in July 2004 and reviewed and revised by Mark Snow in 2011.

Introduction

Solar architecture is not about fashion, it is about survival.

Sir Norman Foster

To make a building zero energy, energy neutral or zero emissions requires not only a very high level of passive design but also on-site energy generation (Marszal et al. 2011).

As time passes, the case for on-site generation only grows stronger. The price of centrally generated electricity is increasing steadily, primarily due to costs associated with augmenting aging network infrastructure. At the same time the cost of PV is dropping as installed capacity grows, bringing greater economies of scale.

The financial driver for the uptake of on-site generation is the return on investment for on-site renewables versus the cost of purchasing conventional utility electricity and gas. Buildings that are less dependent on centralised generation of fossil fuel energy are less exposed to price volatility associated with operational energy costs, especially during peak demand periods. Conversely, buildings that generate their own electricity and can export it to the grid stand to benefit from higher prices.

Not only buildings but towns and cities are looking to transition to decentralised power supply. While large-scale solar installations outside of urban environments offer a solution that fits with a centralised generation model, the economics of transmitting that energy to where it is used can be prohibitive. Solar power in the built environment provides an embedded power source that can be used in situ or by surrounding buildings, offering an efficient power supply that is significantly less exposed than centrally generated power to price volatility.

To date, the majority of solar capacity installed in Australia has been 'slap-on' rack-mounted PV technology, bolted onto roofs. To realise its fullest potential, however, PV needs to be deployed as an integral part of a holistic design solution, adding value not only in the form of electrical energy but also as a building design solution that improves passive performance.

The Autotrophic Building

Energy is an essential lifeline for the construction and operation of cities. Boyden (1979, 1987) provides a succinct description of energy by categorising it into two distinct parts: 'somatic energy' (inside the body), which dates back to the genesis of the first creatures on earth and characterises the flow of energy through living organisms; and 'extrasomatic energy' (outside the body), which involves the flow and use of energy not expended through metabolic processes within living organisms. Autotrophs, such as plants, source energy by absorbing it from solar radiation, while heterotrophs take energy through the consumption of autotrophs (Price 1995).

The decay of autotrophic plant material over many millions of years has provided a concentrated source of combustible extrasomatic energy that human beings, through technological innovation, have been able to exploit at fantastic levels. However we can no longer take for granted an abundance of extrasomatic fossil fuel energy. Population growth, improving standards of living, environmental compliance costs and growing world competition for conventional fuel supplies has meant that our built environments are increasingly hostage to energy price fluctuations.

In situ energy generation can help free the built environment from its reliance on centralised fuel supplies. What is more, the benefits of distributed energy generation flow far beyond individual generators.

As is well known, the running of air-conditioners for cooling during relatively short periods of the summer creates significant investment challenges for energy suppliers to meet demand. The price paid by the highly centralised Australian energy market for securing energy from the wholesale market during peak periods can be as high as, and as of 2011 was capped in NSW at, AU$12.50/kWh.

Against this, solar PV generation directly compliments peak cooling loads in cities and provides significant value to the grid, particularly if it is located at a network hotspot such as a central business district where the grid substations are working hardest to meet building energy demand.

Why BIPV?

Strategies to harness the sun's energy through passive design are widely understood[1]. Energy demand management is essential and is the lowest cost solution to reducing reliance on extrasomatic fossil fuel derived energy. But energy demand management alone will not free us from our reliance on fossil fuels.

[1]See for instance EDG notes 65 EP, 'Climate Responsive Design: Cooling Systems for Hot Arid Climates', and 66 GC, 'Residential Passive Design for Temperate Climates'.

With targets to reduce buildings to zero net energy or even energy plus, there is a genuine momentum for architects to design (or re-design) buildings that not only minimise their energy 'draw', but which generate their own energy. Integrated solar PV is an obvious technology for meeting this 'autotrophic design' challenge.

PV panels that have been installed on top of existing roof structures using a rail or rack mounting system are commonly referred to as building-added PV (BAPV). While this is a simple solution, it is not overly aesthetically attractive and it misses a key benefit of autotrophic design, that of combining energy generation and energy efficiency as an integrated building product.

BIPV not only displaces BAPV but can also contribute to daylighting, noise control and overall thermal performance of a building. The integration of photovoltaics into buildings also offers other advantages over freestanding applications. It eliminates the need for separate support structures or additional land use; it can save materials and produce cost incentives for the adoption of photovoltaic technology. And by enhancing the appearance and desirability of a property, BIPV can improve rental and sales returns.

Figure 2: An example of solar PV used in a heritage setting, at the Vatican City. While this might look like BAPV, the PV panels provide an essential shading function to reduce the heat gain of the public papal audience prayer hall and as such are classified as an integrated element of the building construct.

(Image: Mats Andersson, Energibanken)

BIPV takes what was traditionally just a building's external skin, in weatherproofing and form-making terms, and gives it economic value both as an energy generator and as a visible display of the tenants' corporate values. BIPV has the potential to transform a building in the same way that green roofs have turned the tops of multistorey buildings from platforms for aerials and HVAC plant into desirable outdoor habitats.

For many years, the application of BIPV technology was considered specialised, complex and expensive relative to the installation of building-added PV. There was limited market penetration. Gradually though, roofing and glazing companies began to develop a range of integrated PV products. These products have been slow to enter the Australian market, but as they become standardised and obtain the necessary approval from Standards Australia, this situation will change. Increasingly, Australian designers will be presented with a range of BIPV products offering different sizes, colours, transparency and technology types and combinations of functions.

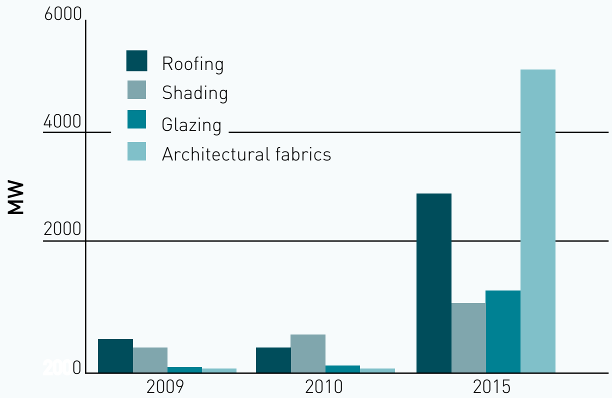

Figure 3: Current and predicted global BIPV sales by application

(Source: BCC research 2011)

Globally, the BIPV market is expected to grow significantly (see Figure 3) as PV product costs continue to fall and products become standardised and incorporated within conventional building practices (Frost and Sullivan 2010). A significant increase in capacity is being driven by European countries offering financial incentives for PV. With additional growing demand from Asia Pacific and North America, BIPV product prices are expected to fall dramatically over the coming years to a forecast US$2.50 a Watt peak (Wp) by 2016 (Pike Research 2009). This equates to around 15 to 20c/kWh – depending on available insolation – on generation value alone.

PHOTOVOLTAICS TERMS

Annual specific yield (kWh per annum/kWp): The actual electrical energy generated by the PV over one year divided by the peak power of the array. This provides a comparison of how well the PV array is performing compared to test conditions

Energy payback time (EPBT): The number of years a PV system has to operate to compensate for the energy it took to produce. Typically EPBT is around one to three years (Fthenakis and Alsema 2006)

Insolation or irradiation: The amount of solar energy incident on a given area over a certain time; commonly measured in kW per m^2 per day and referred to as 'peak hours per day'

Kilowatt hour (kWh): A unit of energy. A kWh is the amount of energy consumed by a 100 watt light-bulb over 10 hours (where 1 kWh = 3.6MJ)

Kilowatt hours peak (kWp): The maximum amount of power a PV module can generate under standard test conditions.

PV standard test conditions (STC): A set of reference PV device measurement conditions consisting of irradiance of 1 kW/m^2, air mass (AM) 1.5, and 25°C operating temperature. Crystalline silicon performance reduces above 25°C operating temperature and as Australian summers are typically hot, so performance of crystalline silicon PV in summer conditions can be expected to be less than STC.

Designing with BIPV

The application of BIPV must be part of a holistic approach to building design and construction. A high-quality PV system can supply a substantial part of the building's energy needs if, in the first instance, the building has been designed to accommodate PV appropriately and to be energy efficient.

Designing with BIPV requires a holistic approach. A BIPV system is a design element of a building and thus should be considered in the very early stages of building concept design. The integration of PV into a building design is not simply the replacement of building materials and components or the resolution of formal aesthetic concerns. Integration will also embrace other functions of the building envelope. Mounted on a sloped roof, a glass PV system can be part of the weatherproof skin, or it can be mounted above a watertight foil to protect it against direct and ultraviolet (UV) sunlight, thereby extending the life of the foil. These kinds of systems are available for flat roofs as well.

PV systems mounted on extruded polystyrene insulation material as a thermal roof system are well suited to the renovation of large flat roofs. PV systems can also be integrated on building elements such as canopies and exterior shading systems. The designer must carefully examine the details of shading and PV technology operation to fully understand how to integrate the PV systems effectively and elegantly.

Heating and cooling loads and daylight control systems can be integrated with PV systems. Moreover, detailed performance studies will discover how BIPV can be an effective and integral part of the thermal envelope or thermal system.

The most important issue for the architect is to become fully conversant with the capabilities of the PV cell typologies and comfortable in finding creative integration possibilities at the early stages of design. A PV system may not be easily or cheaply added to a building that was not initially designed with that intention.

The Design Process

The potential advantages of BIPV will only be realised if the design team itself is integrated. The team will need to work together to decide on the type and mix of PV technology and the resulting electrical output of the installation. Concurrently, the building designer will need to be considering the positioning of the array and the design and layout of the PV modules.

Only concept designs which optimise all of the aesthetic and efficiency potential of a particular technology will be financially feasible. Efficiency and aesthetic characteristics vary considerably in PV technologies and it is therefore important to establish which will be used at a design concept and costing stage. Factors which need to be considered include: electrical efficiency, availability, lead time, capital cost, energy payback time (EPBT), environmental implications, colour, size, translucency, reflectivity and module compatibility.

Photovoltaic Types

Among the various PV technologies presently available, monocrystalline, polycrystalline and amorphous silicon modules are the most commonly used[2]. From a design perspective, the choice of technology type will depend not only on efficiency and cost, but also on flexibility of application and integration.

Monocrystalline PV

Monocrystalline silicon cells are the most electrically efficient, which means they require less surface area than other cell types to produce an equivalent amount of power. They also have a wide range of transparency options. Disadvantages are their higher costs, requirement for ventilation in order to maximise performance, and a distinctive geometric pattern.

Monocrystalline cells are especially suitable for atrium roofs; partial vision glazing in façades, rooftop

[2]See EDG note TEC 4, 'Photovoltaic Cells – How They Work' for further details.

installations in houses and commercial sunshading or rooftop retrofits where installation area is limited and maximum electricity generation is desired.

Polycrystalline PV

Polycrystalline silicon cells are less efficient than monocrystalline, however the lower cost per m^2 and distinctive appearance make this a popular choice for relatively large, opaque installations that serve as a strong design element. They have been used extensively in façade spandrel panels and sunshading elements on commercial buildings.

VENTILATION

Crystalline PV technologies should be ventilated over the back of the module to increase their performance. This is because crystalline PV cells operate better under lower temperatures and ventilation allows heat, which is the by-product of energy generation, to be stripped away. New hybrid systems that capture this heat for other uses and improve PV performance are being developed and referred to as PV-T or PV Thermal systems.

Thin-Film PV

Amorphous silicon cells are based on 'thin-film' technology where a semi-conductor material is deposited on a substrate such as glass. This allows them to be physically integrated in a wider variety of applications, including into flexible membranes and as coatings on ordinary building products. Copper indium gallium selenide (CIGS – or CIS without gallium) and cadmium telluride (CdTe) thin-film PV are growing in market penetration as their manufacturing processes are less costly than crystalline PV's. On the other hand, their efficiency is lower than crystalline PV.

Thin film is less affected by higher operating temperatures and overcast skies than silicon cells. And while a larger surface area is required for output, the cost of electricity per Watt peak is currently more attractive. However if PV material commodity prices, for example the price of tellurium, increase then this could change.

Third-Generation PV

The focus of 'third-generation' PV technology innovation is thin-film technologies that combine the high electrical efficiency of monocrystalline cells with the flexibility and lower costs of manufacturing of thin film. These are expected to provide an increasingly attractive option for building-integrated applications.

Light absorbing dyes such as titanium dioxide and organic polymer solar cells hold promise of a very low-cost PV solution. However they currently suffer from low efficiency output and as yet are unable to maintain their performance characteristics beyond three to five years.

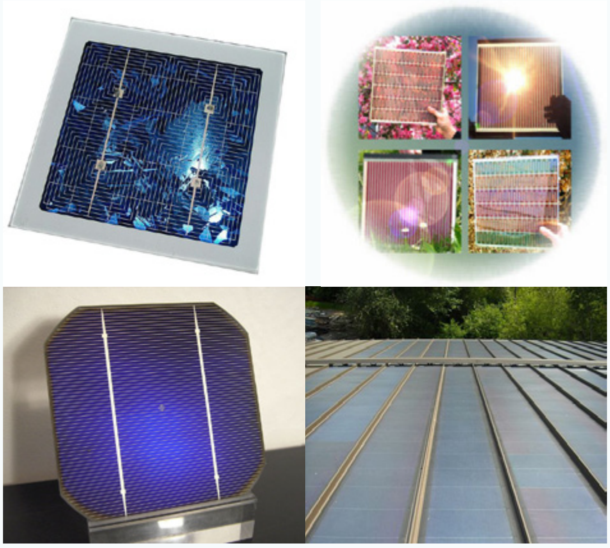

Figure 4: Common PV cell types. Clockwise from top left: polycrystalline cell, dye sensitised (titanium dioxide) cells, monocrystalline cell, thin-film GIS array

(Images: Wikimedia Commons)

PV Type	Description	PV efficiency	Surface area for 1kWp system (m^2)
Monocrystalline (m-Si)	Blue to dark blue, high light absorption	14-19%	7
Polycrystalline (p-Si)	Bright blue and also grey, magenta, cyan	12-15%	9
Thin film amorphous silicon (a-Si)	Reddish-black, very flexible/ durable	6-8%	17
Thin film CIGS/ CIS	Black, shiny cell – flexible or rigid	9-12%	11
Thin film cadmium telluride (CdTe)	Grey-green rigid cell	7-10%	14
Titanium dioxide (TiO2) dye	Light brown translucent window system	3-5%	20

Figure 5: Typical PV types, efficiencies and surface area requirements

Textural Attributes

In monocrystalline modules, the cells can be spaced to allow light transmission or to produce decorative effects, with light transmission anywhere in the range of four to 30 per cent. The layout will need to be negotiated with the manufacturer and will depend on the module shape and the amount of transparency desired. In amorphous silicon, translucency is achieved thorough micro-perforation of the silicon layer. This can allow between 12 and 30 per cent light transmission and appears as a finely striated pattern from the outside; from the inside the appearance is similar to a half-open louvre. The colour of the light transmitted will depend on the colours absorbed by the cell on the way through.

Figure 6: Monocrystalline glazing modules at Daito University, Itabashi Campus, Tokyo
(Image: Ben Nakamura / Yamamoto Hori Architects)

Some thin-film coatings are inherently transparent and can be used in conjunction with a clear glass substrate to allow both visibility and light transmission.

'Pseudo-square' has been the most common shape for monocrystalline cells. These create a diamond pattern between them, which has given rise to the aesthetic most commonly associated with solar modules. However increasingly monocrystalline cells have more shapes to select from.

Amorphous silicon (A-Si) cells are long and very narrow and thus appear more as striations than shapes. From a distance, the cells in A-Si modules are imperceptible and the material takes on a more homogeneous appearance than crystalline technologies. In monocrystalline modules, the cell size provides a distinct scale to the material. Each cell is generally around 100mm^2, but larger sizes are possible.

The typical blue colour of crystalline PV is due to an anti-reflection coating on the top of the cells. Varying the thickness of this coating creates different coloured cells. Standard colour lines for monocrystalline cells include gold, magenta, steel blue and dark blue. If cells are to be used in a transparent module, the coating can be specified as transparent to reduce the opacity of the cell itself. The use of coloured cells lowers the electrical performance of the cell by five to 20 per cent but the trade-off can be worthwhile if it allows PV to be utilised in a particular context. Background laminates can also be coloured and can even provide a luminance effect at night.

Module Edge Treatment

Modules can be purchased and mounted with a frame or as unframed 'laminates'. Framed modules can be attached to a framed substrate using traditional fixing methods while laminates can be held in place with laminate clips, or captured by a mullion, as in traditional curtain wall glazing. The unframed aesthetic has benefits for small-scale applications where the PV will be seen up close, but may not be as important for large-scale applications. Omission of a perimeter frame along the horizontal joints can create the appearance of continuous vertical PV elements. Decorative effects such as fritting have also been incorporated along the edges of frameless modules.

Architectural Criteria for BIPV

A successful BIPV solution requires interaction between building design and PV system design. One approach can be to displace a conventional external building material, such as tiles on a roof or cladding against a façade. An alternative is not treat the PV system as an intrinsic design feature and to place it onto a building element, such as a roof or other fixture.

The integration of PV systems in architecture can be divided into five approaches. It can be:

1. applied seamlessly
2. added to the design
3. added to the architectural image
4. used to determine the architectural image
5. used to explore new architectural concepts

These categories have been classified according to the increasing extent of architectural integration. However a project does not necessarily have to be of a lesser quality just because PV modules have been applied seamlessly. A highly visible PV system is not always appropriate, especially in renovation projects with historic architectural styles. The challenge is to integrate PV modules into buildings properly. PV modules are a new building material that offers new design options. Applying PV modules in architecture should therefore lead to new designs.

Architectural criteria for BIPV are given in Figure 7. These criteria attempt to define and characterise what a good BIPV design might entail. They are not mutually exclusive but provide a basis from which good questions and comparisons concerning the architectural quality of a BIPV project can be made. Further explanation of these points can be found in the sections that follow.

ARCHITECTURAL CRITERIA FOR BIPV

Naturally integrated	The PV system is a natural part of the building. Without PV, the building would be lacking something; the PV system completes the building.
Aesthetically pleasing	Based on a good design, does the PV system add eye-catching features to the design?
Well composed	The colour and texture of the PV system should be in harmony with the other materials. In addition, a specific design of the PV system can be aimed at (for example, frameless versus framed modules).
Grid harmony	The sizing of the PV system matches the sizing and grid of the building.
Well contextualised	The total image of the building should be in harmony with the PV system. On a historic building, tiles or slates will probably fit better than large glass modules.
Well engineered	This does not concern the water-tightness of the PV roof, but rather the elegance of design details. Have details been well conceived? Has the amount of materials been minimised? Are details convincing?
Innovative new design	PV is an innovative technology, asking for innovative creative thinking by architects. New ideas can enhance the PV market and add value to buildings.

Figure 7: Architectural Criteria for BIPV
(Source: Prasad and Snow 2005)

Natural Integration

Natural integration refers to the way that the PV system forms a logical part of the building and how, without a PV system, something will appear to be missing. The system finishes off the building.

The PV system does not have to be that obvious. In renovation situations, the result should look as though the PV system was there before the renovation. The Institute for Marketing building in Figure 8 has a highly engineered, domineering form, whereas in another building a more subtle design might be preferred – and would be equally valid.

Figure 8: 22kW PV System, Institute for Marketing, Upper Austria
(Image: Solartechnik)

Aesthetic Merit

The building should look attractive and the PV system should noticeably improve the design.

To create an appropriate design rhythm, aesthetic integration will depend on the positioning of the array and on the manipulation of colour, texture, transparency, and module and cell sizes. As with any building material, photovoltaics can be used as a design feature or as an invisible system. It is possible to identify a number of distinct theoretical approaches to the integration of photovoltaics in buildings: invisible; additive; integral to the design image; determining the whole design image; and driven by the technology.

The texture of photovoltaic materials at the macro scale is perhaps the most difficult aspect for the designer to handle successfully. If used inappropriately, amorphous silicon products can appear too homogenous and flat; polycrystalline products too highly fragmented; and the pattern of monocrystalline products overbearing, compared with the scale of the application.

In large-scale domestic roof or commercial façade applications, the challenge is to introduce texture without overshadowing the modules. Strategies for introducing texture could include: using stippled glass effects at the module edges; alternating PV modules with other materials; using a light-box detail; using stainless steel laminate clips; combining a variety of

PV technology types; combining a variety of differently specified modules; forward mounting the modules so they cast a shadow on the supporting wall; tilting to allow highlights to be produced; providing non-uniform spacing between cells; exploiting the PV as a homogeneous material to form symbolic shapes. Acid etching of the module's front side glass is sometimes used to reduce reflection in the overall façade and to provide contrast between the PV cladding and the windows.

On houses, the position, form and proportion of PV arrays within the surrounding roofing material needs to be considered. Placing the array directly along the gutter or ridgeline is usually a visually unsatisfactory solution. On the other hand, centring the array between the ridge and gutter line is also not appropriate if only a sliver of roof is being left top and bottom. If the distance between ridge and gutter line is limited, a longer and more narrowly shaped array should be developed. The adoption of a set of proportioning guidelines by councils could assist control of rooftop aesthetics.

If both a solar hot water system and photovoltaic array are to be used, their relationship to each other needs to be considered. The visual benefits of an array that sits flush with the surrounding roof are reduced if a non-integrated solar hot water is placed directly adjacent. If the solar hot water system and photovoltaic array are placed directly adjacent, care should be taken that they do not over-dominate the roof form. Consideration of the relationship between the roof form and the size of solar technologies will overcome these issues.

An Australian Standard has now been developed for the electrical procedure of grid-connection of inverters. There are no other regulations presently operating in Australia relating specifically to BIPV installations. Projects to date have negotiated with their utility on a case by case basis, with different utilities accepting different codes of practice. Normal fire, structural and electrical codes apply.

Figure 9: Conservatory ECN Building 42, Petten, The Netherlands
(Image: Het Houtblad Architects)

Composition

The colour and texture of the PV array should be consistent with the other exterior finish materials. In many cases the PV system will be intentionally produced in a certain way, for example, frameless instead of with a frame. Specific PV technologies can be chosen to achieve a suitable colour, transparency, shape or texture.

Figure 10:43kWp PV glazing façade, Melbourne University, Australia
(Source: STI Australia)

Grid Harmony

The dimensions of the PV system should match the dimensions of the building. This will determine the dimensions of the modules and the building grid lines used. (Grid = modular system of lines and dimensions used to structure the building.)

Figure 11: 89kWp Solargarage Vauban, Freiburg. The mounted PV is aligned to the pylons of the building which extend to the ground.
(Image: Hotz + Architekten)

Context

The BIPV must match the context of the building: the entire appearance of the building should be consistent with the PV system used and vice versa. In a historic building, a tile-type system will look better than large modules. A high-tech PV system, however, would fit better in a high-tech building, as with the Kyushu National Museum example given at Figure 12.

Figure 12: 40kWp Kyushu National Museum, Japan
(Image: Kyocera Solar Corporation)

Engineering

This does not only concern the waterproofing or reliability of the construction. It includes the elegance of the detailing. Did the designers pay attention to detail? Has the amount of material been minimised?

Innovation

BIPV can be used in an infinite number ways. Often international competitions have helped stimulate new design concepts and innovation. Competitions such as the University Solar Decathlon in America, solar car racing events, the virtual World Solar Challenge and many others are inspiring new PV design concepts and technological advancements.

Figure 13: Brisbane's William Buck Centre, designed by Hassell Architects, has an innovative BIPV solution with grid-connected solar awnings
(Image: Hassell Architects / David Sanderson)

In Australia, the energy-efficient Brisbane highrise building William Buck Centre (Figure 13), formally the Hall Chadwick Centre, incorporates 28kWp Cannon amorphous silicon thin film bonded directly to the tin roof. Flabeg 32kWp solar glass laminates act as shading devices on the northern, eastern and western facades. Special control relays isolate individual solar panel strings in case of panel failure. To ensure safety, additional circuit protection was used for the high DC voltages from the roof PV and connections were made at night to avoid dangerous voltages when terminating the PV cabling.

Applications of BIPV

Although BIPV has been in use since the early 1990s, technological advances and the growing collaboration of PV manufacturers and building component fabricators to produce more sophisticated BIPV solutions has increased the options over the last few years.

Residential

Building integrated photovoltaics have been incorporated in individual dwellings and large-scale housing projects throughout the world and there is now a large pool of experience in this area. The most common PV application for houses are small grid-connected rooftop systems from one to 3kWp, which occupy between seven to 15m² of roof area.

In housing energy terms, a five star-rated house with a 1kWp PV system can achieve electricity savings of 80 per cent of the energy consumption of a conventional house. The PV system accounts for about one fifth of this saving and, through substitution of grid electricity, represents a significant reduction in CO^2, especially in terms of displacing the diesel back-up plants that operate when demand is very high.

Figure 14: Century Roof and Solar Installation, California
(Image: Suntech)

Commercial Buildings

In new buildings in Europe, the most popular applications are façade and atrium roof systems that replace traditional cladding materials. Some of the major glass manufacturers now offer an off-the-shelf range of PV glazing modules or total curtain walling systems. Retrofits can also use sunshading systems with integrated PV or rainscreen claddings to enhance the appearance of the building or flat roof mounting systems, concealed behind the parapet.

Vertical Façades

The use of PV modules in façades seems to be obvious. Many façades have glass or tiles as a skin – PV modules can replace these materials. Often façades present large surface areas for PV use, but under a typical vertical profile they are usually sub-optimal in orientation. The extent of this very much depends on latitude, though there are a number of benefits to be gained by using a PV façade approach, particularly for east or west-facing vertical building surfaces that require protection from sometimes very harsh morning or afternoon sun. Façades are, however, more prone to external shading effects and careful site evaluations and shade modelling is recommended to determine solar access.

Façade constructions can be separated into two main groups: ventilated and not-ventilated. Because of the heat build up behind the PV modules, it is important to know whether or not a construction is ventilated. Ventilated façades are suitable for the integration of crystalline silicon PV modules whose output efficiency is sensitive to high temperature. Non-ventilated façades require technologies that can tolerate much warmer ambient temperatures and unventilated conditions.

PV modules can be added to existing walls to improve the aesthetic appearance of a façade. They are simply added onto the structure. There is no need to provide a weather-tight barrier as this role is already performed by the structure underneath the modules.

PV can be integrated into curtain wall systems with single glazing for cold façades. The different curtain wall structures (post-beam structure, structural sealant glazing, spider glazing) give opportunities to explore different framing and appearances. The outer layer of a double-skin façade is also suitable for solar cell integration. PV can also be part of a warm façade by integrating the cells into double glazing that fulfils the requirement of U-values for insulated glazing.

Figure 15: Thin-film curtain wall powered by Kornakas
(Image: Kornakas)

For luxury office buildings, which often have expensive cladding, cladding with PV modules is not more expensive than other commonly used materials such as natural stone, marble and expensive specialty glass. In 2011 this cladding cost around AUD$1,000 per square metre – comparable to the cost of a PV module. Figure 16 represents BIPV costs compared to conventional building materials (Hagemann 2007).

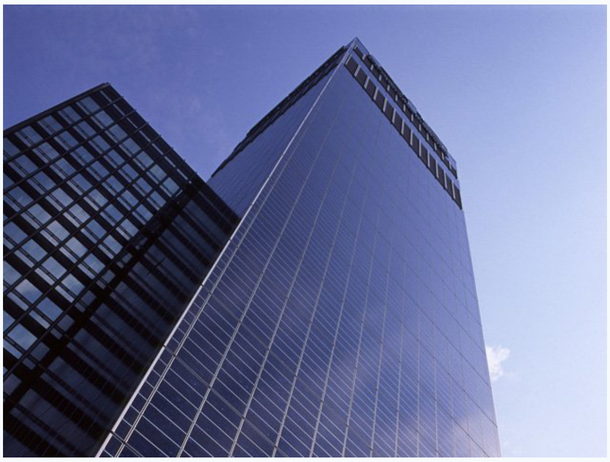

Figure 17: The CIS Office in London was transformed with full use of PV as a façade element with stunning results.
(Image: Solar Century)

Sloped Façades

Sloped façade profiles are particularly practical solutions for optimizing the available PV surface area and can often realize architectural novelty both from an external building form perspective and through the control of and experimentation with passive lighting and active PV structures that are visible from internal spaces. While found primarily on commercial buildings, this approach can be practical for residential applications as a sloped framing louvre construction.

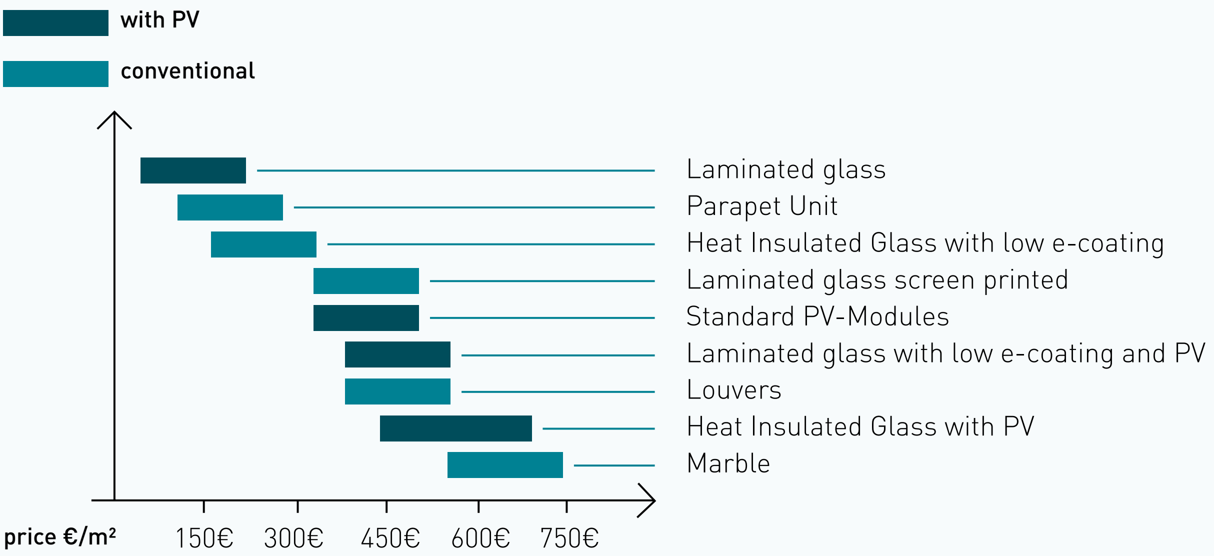

Figure 16: BIPV Costs compared to conventional building material
(Source: Hagemaan et al 2007)

Figure 18: Sloped PV integrated façade, Solar Info Centre GmbH, Freiburg, Germany
(Images: Dr. Klaus Heidler, Solar Consulting)

Balustrades

PVs integrated as balustrades, handrails and ornamental façade fixtures may be applied in both new and retrofit designs. PV balustrade structures create a sophisticated finish to what might otherwise be a bland and uninspiring balcony design.

Shading and Cladding

PV modules can be effectively incorporated into eaves as a continuation of a roof line or an overhead screening device. Against glazing façades, this can produce vibrant PV mirror reflections from the streetscape, visually appealing from within the office space or externally.

Glass PV laminates, replacing conventional cladding material, are basically the same as tinted glass. They provide long-lasting weather protection and can be tailor-made to any size, shape, pattern and colour. PV modules can be also configured as a multifunctional building element.

Note that where translucent modules are used in awnings and canopies, the detail design of the supporting structure is critical, to enable it to integrate or hide electrical wiring.

Shading and cladding systems, particularly on façades, can be used to help reduce unwanted thermal gain and increase electrical generation. PV can be used as a whole building structure solution as demonstrated in the Okinawa 195 kWp example at Figure 20, to shade the building and maximise its power generation potential.

Figure 19a: PV awnings, Kogarah Town Square, NSW
(Image: Kogarah Council)

Figure 19b: PV awnings, Gold Coast Stadium, Qld
(Image: Stoew Engineering)

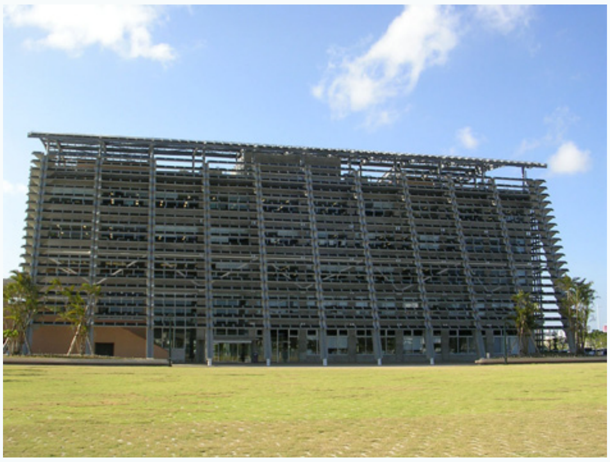

Figure 20: Itoman city government building, Itoman, Okinawa, Japan
(Image: Mizuho Information & Research Institute)

While this is perhaps an over engineered example, it shows what is possible. Importantly, if designed correctly the BIPV will improve the indoor environmental quality (IEQ). However, there is a careful balance to be struck to ensure BIPV does not limit natural daylighting provision or panoramic view.

Glazing

As well as transmitting daylight, translucent PV modules used as roofing and façade materials serve as water and sun protection. In glass-covered areas, such as sunrooms and atriums, sun protection in the roof is necessary in order to avoid overheating in summer. PV cells absorb 70 to 80 per cent of the sun's radiation. The distance between cells can range from 5mm to 20mm. The space between the cells will transmit enough diffuse daylight to achieve a pleasant lighting level in the area.

Figure 21: Translucent PV modules at Daito University, Itabashi Campus, Tokyo
(Images: Ben Nakamura / Yamamoto Hori Architects)

Retrofits

Increasingly, older commercial buildings are lending themselves to BIPV retrofits. Often the revaluation of a property and increased asset value pays for the PV integration from day one. BIPV can reinvigorate a drab building into something that is fresh and modern, and make a building more likely to appeal to prospective tenants.

Figure 22: North Devon District Council, Barnstaple, 56.6kWp retrofit transforms an unattractive 1970s office block
(Image: Garry Whitaker)

Where a heritage overlay presents a challenge to PV integration, the amorphous-module grey colour has been found to blend in well with slate tiles; and may be successfully introduced without adversely impacting heritage appearance.

Figure 23: Heritage building retrofit with Solar Century C21e Roof Tile, UK
(Image: Solar Century)

Solar Access

The amount of solar access received by the photovoltaic modules is crucial to the financial feasibility of any BIPV proposal. Latitude is a primary factor. In Australia, high levels of insolation and generally fine weather allow installations almost half the size of counterparts in Europe to generate the same amount of electricity.

An orientation of north with a tilt-angle of about 30 degrees will generally provide the maximum amount of electricity over a year. In building integrated applications, it may be justifiable to trade-off this optimum tilt and orientation with other design considerations. For instance, on a large building with a BIPV façade, the cost, aesthetic and maintenance benefits of a standard vertical façade may offset the energy lost by not having an optimum tilt (almost one third). Similarly, commercial buildings which purchase electricity with a 'time of use' tariff, may also consider orienting PV to generate electricity at 'peak times' to reduce the amount of electricity that the building needs to purchase at the peak rates. Figure 24 shows that at latitude 35°S (Adelaide and Canberra), PV oriented away from optimum has a high tolerance before it begins to suffer significant reductions in performance.

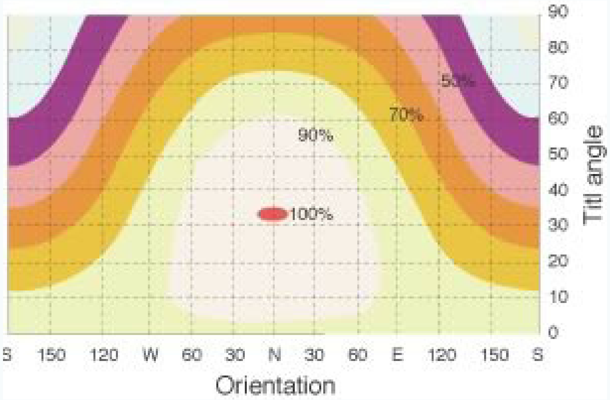

Figure 24: Variation of solar module output with orientation and tilt angle for latitude 35°S
(Source: Your Home Technical Manual)

Overshadowing

An important consideration when designing in BIPV is the implications for overshadowing and the future height of surrounding buildings .

Ideally, a PV array should be fully and homogeneously illuminated, both for cost efficiency and to simplify the electrical design. In large-scale applications, it may be warranted to have BIPV partially overshadowed in order to achieve other design goals such as proportion, harmony etc. In this situation, the overshadowing and its impact on the arrays will need to be carefully modelled at feasibility stage and as the design develops. The electrical grouping of individual modules will also require careful consideration by both the designer and electrical consultant at concept stage. For isolated, narrow shadows, long amorphous silicon cells, which are less likely to be overshadowed over their entire length, may provide some benefits.

Figure 25: Example of partial shading, Kogarah Town Square
(Image: Mark Snow)

Summary

There are many ways in which PV can be incorporated in buildings. As the technologies become more efficient and more mature, a broader palette of module types and integration systems is becoming available to designers. Successful solutions will require an awareness of the parameters of the material and the adoption of a methodology that allows energy, construction, cost and aesthetic factors to be jointly evaluated and modelled at concept level. By gaining an understanding of the primary issues now, building designers will be in a position to evaluate new technologies as they emerge, and to participate in guiding the more widespread adoption of the technology in the future.

As a final note, design integration of BIPV cannot be achieved if off-the-shelf products are applied without due consideration of their local context. Many products reflect common residential aesthetics in their respective countries and will not necessarily suit residential applications in Australia. Quality control, durability and cost factors in the Australian building sector may also present a barrier to overseas products which make extensive use of rubber sealants in roofs, cause heat accumulation or require intricate fixing systems.

The best solution is to develop greater awareness of existing products to provide a starting point for developing systems that suit Australian needs, and then to sponsor Australian products through the joint collaboration of building designers and PV manufacturers. This is likely to occur with increasingly frequency in the next few years as the local market increases, with the local production of new thin-film technologies and the streamlining of existing technologies.

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