EU framework programme

eco buildings

Integration of PV into the built environment

Guidelines

2007

1. Introduction

Generating electricity with a photovoltaic (PV) system has many advantages. Photovoltaic systems are sustainable, environmentally friendly, quiet, light and require minimal maintenance as they have no moving parts. PV systems are made up of modules (or panels), which give the system the flexibility to be expanded or reduced to suit any given application. The versatility of PV panels gives numerous possibilities for their integration into new and existing structures.

While the installation of PV panels on flat and tilted roofs is perhaps the most popular example of its application in buildings, the integration of PV into facades also offers tremendous potential, as exemplified in Figure 1. Integrating PV into new and existing architecture offers great possibilities for the design of energy efficient and ecologically sound buildings, without compromising comfort or aesthetics.
In addition to design benefits, PV integration offers a number of cost benefits. Integrated PV panels generate electricity and acts as part of the building fabric. This combined function can result in costs savings where the cost of traditional building fabric is comparable to that of the PV panels. Also, no additional land or separate support structure is required, giving further cost advantages.

Currently, a typical PV system currently produces electricity at approximately four times the cost of conventionally produced electricity. However, the cost of producing electricity from PV has fallen by over 50% in the last ten years as a result of constant improvements in PV technology, integration techniques and increased production volumes. With this downward trend set to continue against a background of rising oil prices, the economic benefits of PV will continue to rise.

Building Integrated PV helps designers to meet goals of sustainability and reduced emissions while maintaining or improving comfort. The synergy between integrated PV’s main functions of on-site energy generation and forming part of the building fabric, along with increasing cost competitiveness makes integrated PV an especially attractive option.

2. Regulations and standards

Regulations and standards exist to protect the integrity of the PV system and ensure it is installed correctly. Many standards exist to ensure PV systems are fit for purpose when correctly installed. The vast majority of building integrated PV systems are connected to the grid and many countries have developed regulations to ensure systems are installed appropriately. However, standards are largely country specific, hence, it is important to ensure that all PV systems comply with the relevant regulations, electrical installation requirements, standards and code of practice appropriate to the country.

Figure 1 - The Solar Wall at the Welsh Development Agency "Technium" in St. Asaph, North Wales

3. Current Practice

Traditional installations of solar components into buildings can use standard modules or specially designed glass-glass laminates, either as completely independent structures or in the best cases, superimposed on existing parts of the building such as roofs and façades.

3.1. Photovoltaic cells

Although the most commonly used cell types come from the same base material, silicon, different technologies offer cells with different technical and aesthetic characteristics.

Monocrystalline cells are 10 x 10 cm^2 and 350 micron in thickness with an efficiency of up to 14-17%. They produce, on average in European weather, 900-1000 kWh per each kW installed.

Polycrystalline cells with equal dimensions reach a performance of up to 12% and would produce on average 750-850 kWh per each kW installed.

Amorphous or thin-film silicon is a very different technology. A very thin layer of silicon (several micron wide) is deposited on top of glass with a transparent metal coat. These cells have efficiencies up to 5-8% and would produce in average 600-800 kWh per each kW installed

The latest technologies offer crystalline cells in a range of colours and new base materials, such as Gallium-Arsenide (GaAs), Cadmium-Telluride (CdTe) or Copper-Indium-Diselenide (CIS). PV cells are joined together then protected by means of encapsulation with front glass and back protection, resulting in PV modules.

3.2. PV modules

PV modules are designed for outdoor conditions, so they are able to be part of the building skin. However, different encapsulation technologies result in a range of PV panels having different performances as a constructive element.

a) Glass-plastic back sheet. The transparent adhesive is usually EVA (Ethal-Vinyl-Acetate), and the back sheet TedlarTM in different colours, translucide or transparent.

b) Glass-glass. The back sheet is substituted by another glass. The transparent adhesive can be also made by resins.

Standard modules have an Aluminium frame. Modules without a frame, also called "laminates", are more commonly used for building integration.

Several module manufacturers offer customised modules with flexibility in size, shape, cell types and cell arrangement, allowing larger creativity and flexibility for fulfilling the particular architectonic requirements of a building.

3.3. Integration of PV modules in buildings

The solar area should be directed towards the sun for optimal energy generation. Hence, PV systems should be south facing in the northern hemisphere and north facing in the southern hemisphere. It is also important to ensure the solar area is shadow free. In all the cases the area should be adapted to the building architectonic requirements (e.g. transparency, thermal insulation) and the cost of the substituted constructive materials taken into account. The cost of a façade is usually higher than that of a roof installation (see Figure 3), partially compensating the lower irradiance. Figure 2 below shows a schematic of the various ways PV modules can be integrated.

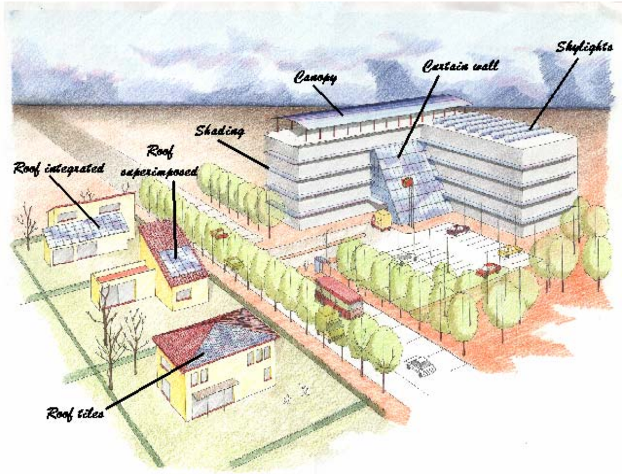


Figure 2

3.4. Integration Methods

PV systems can be incorporated into buildings by either superimposition - where the system is attached over the existing building envelope, or integration - where the system forms a part of the building envelope.

Superimposed

This is a simple method well suited to existing buildings. The solar panels are mounted on a structure on the building envelope and in parallel with them as shown in figure 3.The visual impact on the building is minimal as depicted in figure 4. No savings in substituted elements is achieved.

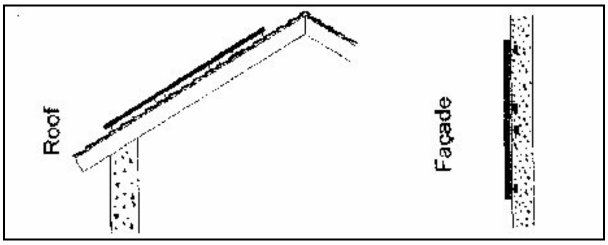


Figure 3

Figure 4

Integrated

This method uses the solar collector as an architectural function as well as a means of energy generation. It is most suitable for new buildings. The traditional constructive elements are substituted for PV materials. Savings are possible where the cost of the substituted elements is below that of the traditional elements. It offers a pleasant and clean appearance. The most common integration techniques are discussed in the following sections.

Overcladding (cold roof or façades)

An external layer is created by solar collectors as shown in figures 5 and 6. Waterproofing material is placed over an opaque layer which ensures thermal insulation. Solar PV tiling is a special technique for roof integration. Sufficient ventilation of the PV modules is essential for optimal cell efficiency. The savings are significant.

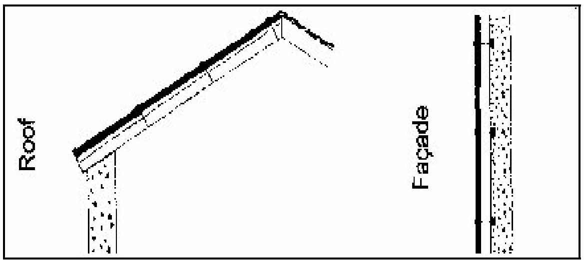


Figure 5

Figure 6

Enclosure (hot roof or façades)

In this scenario the solar collector acts as the roof or façade (as shown in figures 7 and 8).

For PV, adapted conventional glazing systems are used (mullion-transom or structural glazing). An advantageous characteristic of this system is a double envelope including a ventilated chamber which improves the thermal performances and allows capturing warm air for heating purposes. The savings are optimal.

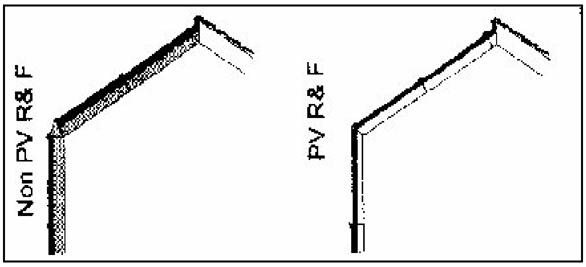


Figure 7

Figure 8

Shadow devices

These are best suited to PV applications due to the heaviness of the water and air solar collectors. Solutions such as blinds or awnings provide shading to the interior space, shielding direct sun while allowing diffuse, indirect light. They work well with tracking systems to optimise the generated PV electricity. Figures 9 and 10 illustrate this system. The savings are significant.

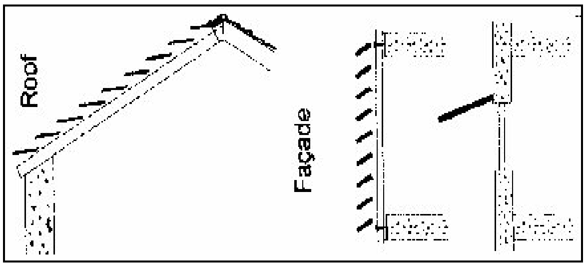


Figure 9

Figure 10

4. Innovative Solutions

There are many innovations in the field of the building integrated photovoltaics. The main innovations arise from the use of PV as the outer cladding and the detailing of facades to accept this new material and mounting systems. A brief overview is given below.

4.1. Pure Curtain Wall

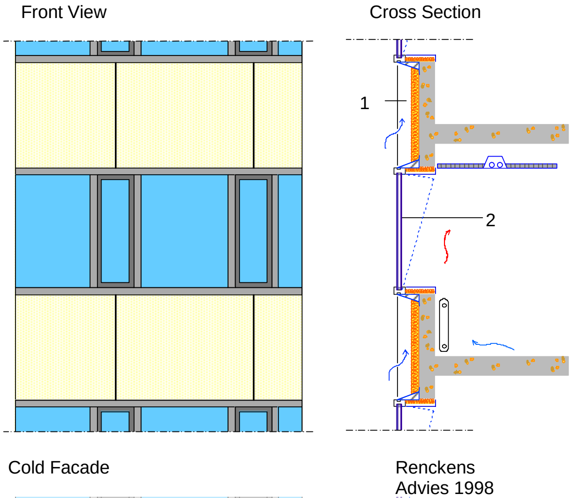
When the entire facade is completely and continuously erected in front of the supporting skeleton, the facade is referred to as a curtain wall. A curtain wall is a self supporting construction so that the framework carries its own weight and supports the wind loads to the skeleton construction. It is the only barrier between the inside and outside climate. The pure curtain wall is assembled out of glass and aluminum and it is usually mounted using the stick system or ladder mounting technique. Generally, these type of facades are applied in buildings with large glass facades, e.g. at the entrance hall.

4.2. Ventilated Facades

PV-ventilated facades are double facade constructions which combine the advantages of cooling the PV modules using ambient air with the potential to use the hot air so produced for heating and cooling of the building. Ventilating building integrated photovoltaic facades is 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. Within warm facade constructions, where the PV element forms an integral part of the building's envelope, lower PV module temperatures also imply lower wall or glazing temperatures behind the module and consequently lower cooling loads of the façade in summer. Furthermore, a controlled air flow behind the PV facade leads to potential uses of the warm air for winter preheating or summer cooling.

4.3. Cold Facade

The cold facade is a curtain wall with a cold ventilated cavity wall. The ventilation in the cavity wall is achieved by open seams in the facade, which allows ambient air to enter the cavity as depicted in figure 11. The facade 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 facade is usually mounted using the stick system or ladder mounting technique.



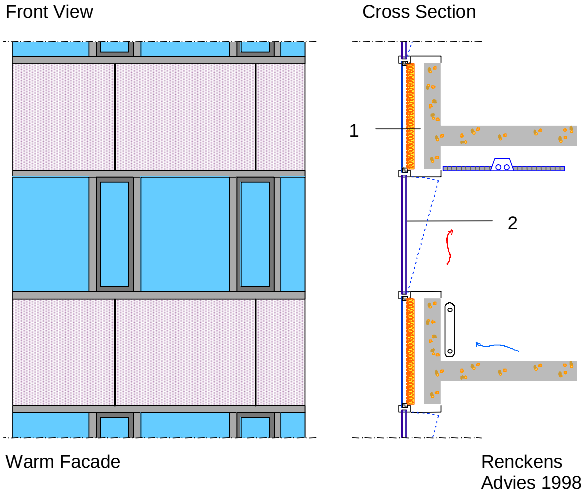
Renckens Advies 1998

Figure 11

1. ventilated cavity by ambient air (pressure equalization)
2. insulated window pane (fixed or to be opened)

4.4. Warm Facade

The warm facade is a curtain wall with an unventilated warm cavity wall as shown in figure 12 below. The warm cavity is attained by the water and air tightness of the insulated outer skinfaçade. The outer skin of the warm facade 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 component in large component mounting.



Renckens Advies 1998

Figure 12

1. closed warm air cavity
2. insulated window pane (fixed or to be opened)

4.5. Climate Facade

The climate facade eliminates ambient influences but maintain clear visual sights and the admittance of day light. It is composed of an insulated exterior wall (glass and spandrel) and interior non-insulated wall (concrete building skeleton and single glass pane) as depicted in figures 13 and 14 respectively. The exterior wall is attached to the building skeleton by a profile mounting system for which the component and large component mounting techniques are usually used.

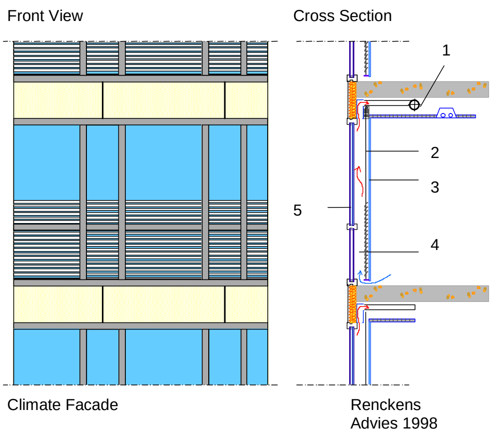


Figure 13

1. mechanical ventilation system
2. sun and daylight control in the inner cavity
3. single glass pane, to be opened for cleaning purposes
4. cavity (interior air extraction)
5. insulated window pane

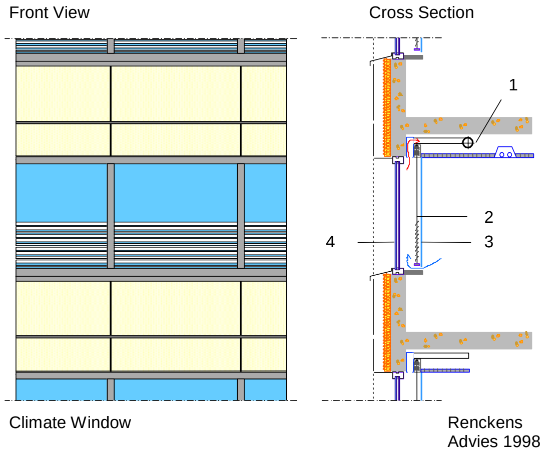


Figure 14

1. mechanical ventilation system
2. sun control in the inner cavity
3. single glass pane, to be opened for cleaning purposes
4. insulated window pane

4.6. Second Skin Facade

The curtain wall of the ‘second skin’ type is a new concept, developed in the nineties, which closely relates to the climate facade. Whereas the climate facade completely protects the interior climate from the exterior climate, the second skin facade links the interior climate to the exterior by a buffering zone. The second skin facade excludes the influences of heat, wind, humidity, sound in the ambient surroundings from the interior. Only sun and daylight are allowed to penetrate into the building in a controlled way. Sunlight enters the cavity of the second skin facade and is converted in thermal energy, which is distributed through the building by air-conditioning or ventilation units. The air-conditioning unit controls the ventilation, heating and cooling demands of the building. In other words, the second skin links the exterior to the interior climate. These types of facades try to extract as much (solar) energy as possible from the exterior.

The second skin facade is developed from the background of the conscious ecological assessment and of environmental loads of the raising energy consumption. Also the need for more open interior spaces and a more natural transparency are considered to be important features. This system is depicted in figures 15 and 16.

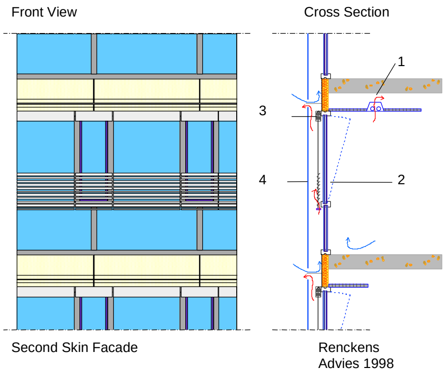


Figure 15

1. plenum (air extracting)
2. insulated window pane
3. sun control in outer cavity
4. single glass pane

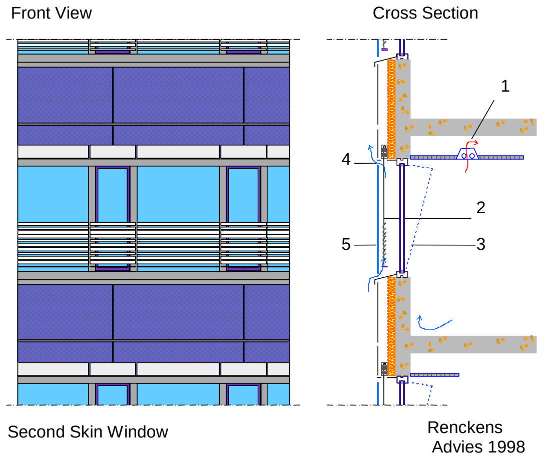


Figure 16

1. plenum (air extracting)
2. sun control in outer cavity
3. insulated window pane
4. void (pressure equalisation)
5. single glass pane

Compared to the climate facade, the double and single glass panels have changed position and the cavity is not ventilated mechanically anymore. The second skin facade is a skin of single glass panes in front of an insulting inner facade. The outer skin acts as rain (pressure equalisation) and wind barrier. The cavity in between the outer and inner skin may vary in size, in general the width is in the range of: 200 – 350 mm (small cavity), 550 – 750 mm (accessible for cleaning) and 1000 – 2000 mm (accessible for public). Independent of the width of the cavity, the cavity holds the sun regulating devices and is ventilated naturally by ambient air.

Advantages of the second skin facade above the climate facade are:

- the additional glass shell and the wide cavity forms a climatic buffer
- the inner building facade is fairly well protected against ambient influences
- windows can be opened, even at a great height
- noise barrier with respect to airborne sounds

As the construction principle of the second skin facade is derived from the climate facade, the used mounting techniques are closely linked to the mounting techniques of the climate facade. For the interior wall usually the component and large component mounting technique are used. The exterior wall, the single glass wall, is mounted according to the stick system or ladder technique.

4.7. Triple Skin Facade

A further development on the second skin facade is the triple skin facade which combines the second skin with a textile screen at the inside of the inner wall (third skin) as shown in figure 17. The textile screen acts as an extra sun and daylight regulating device. The triple facade combines the advantages of the climate facade and the second skin. The climate facade operates best during peaks of heat (summer) and cold (winter), whereas the second skin facade is more comfortable during the long seasons in between and consumes less energy.

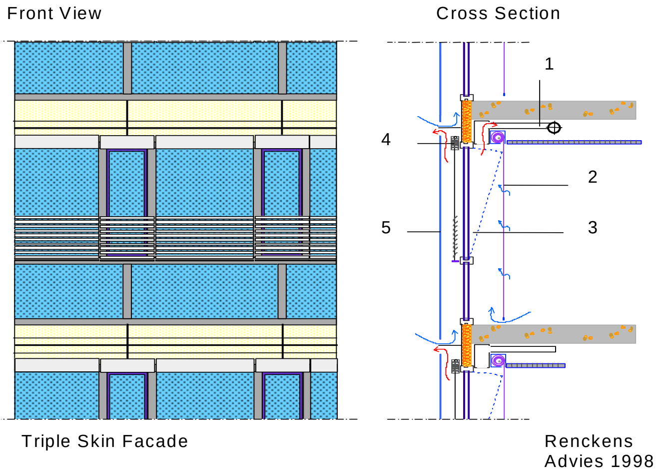


Figure 17

1. mechanical ventilation system (air extracting)
2. textile screen (interior control sun and daylight)
3. insulated window pane
4. sun shading device (exterior sun control)
5. single glass pane

5. Benefits of integrating PV into the built environment

The value of building integrated PV (BIPV) systems can directly affect the decision making process. These benefits can be identified and evaluated based on direct economic impact, indirect economic impact, and qualitative value.

5.1. Direct economic impact

An integrated building energy system is generally procured through a construction budget. Electricity generated by the BIPV system creates reduced the amount of electricity purchased from the grid, reduce operating costs. A BIPV system can also save the building owner money by reducing construction costs, enhancing power quality and power reliability, and providing tax credits. The combined savings may accrue in a variety of budgets that will affect the investor’s entire fiscal portfolio performance.

5.2. Indirect economic impact

Each building owner has a value related to strategic goals, business interests, or organizational mission. With a multifunctional BIPV system, additional costs and benefits may accrue and may be hidden or not obvious, due to accounting methods and the directly and indirectly affected 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.

5.3. Qualitative value

Some benefits of BIPV systems are subjective and are difficult to quantify. For the building owner, a considerable value of a BIPV system may be associated with a positive image, public perception, or impact on the built environment when the technology is installed. Table 1 gives an overview of the factors that can add value to BIPV systems.

Table 1 - Factors that can add value to BIPV systems.

Category	Potential Values
Electrical	KWh generated; kW capacity value; peak generation and load matching value; reduction in demand for utility electricity; power in times of emergency; grid support for rural lines; reduced transmission and distribution losses; improved grid reliability and resilience; voltage control; smoothing loan fluctuation; filtering harmonics and reactive power compensation
Environmental	Significant net energy generator over lifetime; reduced air emissions of particulates, heavy metals, CO2 , NOx, SOx resulting in lower greenhouse gases, reduced acid rain and lower smog levels; reduced power station land / water use; reduced impact of urban development; less nuclear safety risks
Architectural	Substitute building component; multi-function potential for insulation, waterproofing, fire protection, wind protection, acoustic control, daylighting, shading, thermal collection and dissipation; aesthetic appeal through color, transparency, non-reflective surfaces; reduced embodied energy of the building; reflection of electromagnetic waves; reduced building maintenance and roof replacements
Socio-Economic	New industries, products and markets; local employment for installation and servicing; local choice, resource use and control; potential for solar breeders; short construction lead-times; modularity improves demand matching; resource diversification; reduced fuel imports; reduced price volatility; deferment of large capital outlays for central generation plant or transmission and distribution line upgrades; urban renewal; rural development; lower externalities (environmental impact, social dislocation, infrastructure requirements) than fossil fuels and nuclear; reduced fuel transport costs and pollution from fossil fuel use in rural areas; reduced risk of nuclear accidents; symbol for sustainable development and associated education; potential for international cooperation, collaboration and long-term aid to developing countries
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 characterised by relatively small generation units located nearby the consumers that uses the locally available energy resources. Consequently, generation and consumption processes take place locally. This enhances the security and reliability of the grid and also enhances power quality, which is increasingly important for electronic equipment.

Source: “Added Value of PV Power Systems”, Report IEA PVPS T1-09: 2001

6. Costs

The cost of the BIPV system depends on the type and size of system, on current PV technology, and on whether a customised or standardised product is used.
BIPV systems are composed of PV modules and balance of system (BOS) components which include inverters, an electricity storage system and/or a grid-metered connection, fault protection, cabling and wiring. These costs, as well as the costs of system design and installation, should be compared against traditional construction products and systems in order to determine the marginal cost of the BIPV system.

6.1. System and components

Currently, PV manufacturers are in the early stages of technology development and commercialization and do not have the capacity to take advantage of quantity purchases of materials and of large volume production in order to offer lower-priced BIPV components and systems. Nevertheless, there has been a decline in the cost of PV technology over time due to technical advances. In addition, the industry and government foresee further cost decreases as the demand for PV technology increases internationally and manufacturing economies of scale increase.

6.2. Installation

BIPV can be incorporated into new constructions at a relatively small additional cost. When compared to more conventional cladding materials such as glass or steel, installing solar photovoltaics adds a marginal 7% - 10% to the total construction costs of a commercial building. Until BIPV becomes a mainstream technology, there will be additional labour costs for architectural design, engineering design, and installation. Installations can be done by traditional building tradesmen (including glaziers, roofers, sheet metal workers, and electricians) under technical supervision or may be contracted specifically for this purpose. Care should be taken to include these costs in the evaluation of a BIPV system.

6.3. Connection

Utility grid interconnection costs are associated with the specific requirements of the respective country. Utility companies have widely varying attitudes toward additional requirements. Costs can include interconnection fees, net metering tariffs, metering calibration charges, engineering study fees, and standby charges. Additional requirements for liability insurance, property easement, legal indemnification, record keeping of all operations and maintenance (O&M) activities and additional protection equipment will contribute to greater utility interconnection costs. The relative cost of meeting these requirements is much higher for small systems than it is for larger systems. The cost of these requirements offset to some extent the incentive provided by net metering and may deter customers – particularly small power customers – from participating.

7. Maintenance and service

Periodic system checks and cleaning is recommended as part of a preventive maintenance routine. This includes clearing away debris and cleaning the PV surfaces exposed to the environment at regular intervals. To determine the optimal cleaning schedule, the trade-off between the cost of cleaning the system to maximize power output and the value of the lost electricity without cleaning the system can be assessed. In some instances, particularly in high-rises or buildings with unusual geometric shapes, cleaning the system can be more costly than the reduced power output. As a rule of thumb, visual inspection of essential components, based on an inspection checklist provided by the manufacturer, should be made every six months.

Annual detailed electronic testing is recommended. The string voltage can be tested with a voltmeter. (A string that shows low voltage relative to the others may have a faulty module or connector.) A data logbook should be maintained by the facility maintenance personnel to record system performance, maintenance, and string voltage. Service adjustments and repair can be provided by the manufacturer, system integrator, distributor, or potentially by the utility company.
Training the facility engineer to service the system in-house will minimize the cost for system maintenance.

8. Calculation tools

There are three computer based design tools which are particularly suitable for the design of building integrated PV systems.

1. PVSyst was developed at the University of Geneva and is a PC software package for the study, sizing, simulation and data analysis of complete PV systems. It is suitable for grid-connected, stand-alone and DC-grid (public transport) systems, and offers an extensive meteorological and PV-components database. This software is aimed at architects, engineers, and researchers, and is also useful for teaching purposes.
2. The ALLSOL PC program developed by Solpros from Finland and Helsinki University of Technology is an all-in-one pre-design tool for building energy systems which also includes BIPV systems. It takes into account the interplay and interaction between different components, e.g. BIPV and the building thermal performance. The PV is not only an electricity production unit, but may also interact with the heating, cooling, and daylight energy flows of the building. The designer may seek for the best combination of different technologies using a variety or combination of different criteria.
3. REETSCREEN

   The RETScreen® International Photovoltaic Project Model can be used world-wide to easily evaluate the energy production, life-cycle costs and greenhouse gas emissions reduction for three basic PV applications: on-grid; off-grid; and water pumping. For on-grid applications the model can be used to evaluate both centralgrid and isolated-grid PV systems. For off-grid applications the model can be used to evaluate both stand-alone (PV-battery) and hybrid (PVbattery- genset) systems. For water pumping applications the model can be used to evaluate PV-pump systems.

9. References

9.1. Compilation

This guideline is written as a part of the project BRITA in PuBs – Bringing retrofit innovation to application in public buildings, EU 6. framework program Eco-building.
The author is Manuel Fuentes, UK. The professional editing was closed in October 2007.

9.2. Literature

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