22

PV in Architecture

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22.1 INTRODUCTION

22.1.1 Photovoltaics (PV) as a Challenge for Architects and Engineers

What is happening in the built environment around us? We are witnessing an essential change in society. Governments are spending hundreds of millions of dollars on research, development and the demonstration of renewable energy. Big oil companies such as BP Amoco and Shell have invested more than a billion dollars in solar energy. Current developments show that renewables, such as solar energy systems, will be incorporated into our daily life in the near future, as conventional energy sources become depleted and environmental concerns grow [1].

Within a short period of time, solar systems will become an integral part of our society and thus our environment. There are large incentives for urban planners and architects to incorporate these techniques into their design. New products are emerging yet need further development to fully meet the architectural needs of sustainable buildings. Architects therefore need to start thinking about this new Smart Solar Architecture.

The European Commission has issued the "White Paper for a Community Strategy and Action Plan, Energy, for the future: Renewable Sources of Energy" [2]. This White Paper sets a target of 12% for the contribution of renewable energy sources to the total energy consumption in the European Union by 2010. The "Campaign for Take-Off" was launched in 1999 and aims to facilitate the success of the Strategy for Renewable Energy Sources up to the year 2003. One of the proposed key sectors to be promoted during the campaign is PV systems – 1 million systems in total.

The 450 MWp rooftop system campaign in the European Union can be achieved by installing 150 000 systems at an average capacity of 3 kWp each. The 150 MWp

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building facades program in the commercial sector can be realized by installing 5000 systems, assuming an average size of 30 kWp per building. With an additional capacity of 50 MWp for stand-alone systems the total target for installed PV for Europe will be 650 MWp (approx. 6 500 000 m^2).

22.1.2 Definition of Building Integration

A large part of the future PV market will be associated with building applications, especially in Europe and Japan where the population density is high and the land is valuable [3]. In areas with less population, it will be possible to find land for ground-mounted PV structures (Figure 22.1) [4].

Building-integrated, grid-connected PV systems have the following advantages [5]:

- There is no additional requirement for land.
- The cost of the PV wall or roof can be offset against the cost of the building element it replaces.
- Power is generated on site and replaces electricity that would otherwise be purchased at commercial rates.
- Connecting to the grid means that the high cost of storage is avoided and security of supply is ensured.

Additional benefits of public awareness are [6] as follows:

- Architecturally elegant, well-integrated systems will increase market acceptance.
- Building-integrated PV (BIPV) systems provide building owners with a highly visible public expression of their environmental commitment (Figure 22.2).

Figure 22.1 The 1 MWp ground-mounted system in Toledo, Spain. Reproduced with permission by BEAR Architecten T. Reijenga

Figure 22.2 Integrated façade system with 14 kWp amorphous silicon modules made by Energy Photovoltaics (EPV) in New Jersey, USA on top of a skyscraper at Four Times Square, New York, USA. The PV modules are the dark regions on the facade near the top. Reproduced from Kiss G, *Proc. 2nd WC Photovoltaic Solar Energy Conversion*, 2452–2455 (1998) with permission by Gregory Kiss [7]

The way people deal with photovoltaics in architecture differs from country to country. This depends on the scale, culture and type of financing for building projects. In countries such as Denmark, the Netherlands and the United Kingdom, where public housing is very common, serial production is strongly emphasized in housing projects. Professionals such as project developers and architects implement the housing construction process, in which the main opportunities are for PV roof integration in single-family terraced houses and for façade and roof integration in apartment buildings.

In countries where the government has little influence on house building, the building process is a private initiative. Integration of PV systems in buildings can be carried out by professionals but, on the smaller scale of a single-family house, the motivation must come from the private owner. In these countries, most building-integrated PV systems are found in commercial and industrial buildings in which building professionals are involved. With these types of buildings, PV systems are integrated both into façades and roofs. There is a significant market for private homeowners who buy small-scale (less than 500 Wp) PV systems and mount them somewhere on their house.

The aim of integrating PV systems into buildings is to reduce the requirement for land and the costs [8]. This could be the cost of the support construction and the cost of building elements, such as tiles. It is more efficient to integrate a PV system when constructing the building, rather than mounting it afterwards.

A definition for Building Integration is hard to formulate, as it concerns the physical integration of a PV system into a building, but it also covers the overall image of the PV system in 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 BIPV system. In fact, many examples of physical integration show a lack of aesthetic integration. Visual analysis of PV systems in buildings shows that the look of a poorly designed building does not improve, simply by adding a well-designed PV system. On the other hand, a well-designed building with a nicely integrated PV system will be accepted by everybody.

The following section aims to explain some basic thoughts about PV to non-designers, from an architectural and design point of view.

Note: All specified power of PV systems is the power under standard test conditions and tilt which may be greater than the power delivered when installed in nonoptimum orientation required by the BIPV application.

22.2 PV IN ARCHITECTURE

22.2.1 Architectural Functions of PV Modules

Basically there are three locations for integrating PV systems into buildings. The main locations are the roof and façade, with all other locations being known as *building components*.

A PV system can be integrated into the roof in several ways. One choice is for the integrated system to be part of the external skin and therefore be part of an impermeable layer in the construction. In the 1990s, several building projects were constructed on the basis of this principle (Figure 22.3) [9]. The other choice for roof mounting the PV system is above the impermeable layer. This is a more secure option but not without some risk, as the impermeable layer has to be pierced in order to mount the system on the roof. Using PV modules as roof covering reduces the amount of building materials needed, which is very favorable for a sustainable building and can help reduce costs. In addition to covering the complete roof with modules, there are also many products for small-scale use, for example, PV shingles and tiles. The small scale of these products (from 2 cells on a tile to around 20 cells on a look-alike tile) makes them very convenient for use in existing buildings or as do-it-yourself products.

Figure 22.3 Roof integration in a renovation project with the Shell Solar/BOAL profiles in Leiden (NL), providing a 2.1 kWp system per house. The PV roof is an impermeable layer. Reproduced from Maycock P *et al.*, *Building with Photovoltaics*, 78–81, Ten Hagen & Stam, Den Haag (1995) with permission by NOVEM, R Schropp [10]

Figure 22.4 Solar office in Doxford Sunderland (UK) with a transparent double-glazing PV system integrated in the façade. The 73 kWp PV system is manufactured by Saint Gobain and mounted in Schüco window frames. Reproduced with permission by Dennis Gilbert

Transparent PV modules used as roofing materials serve as water and sun barriers and also transmit daylight (see Figure 22.4). In glass-covered areas, such as sunrooms and atriums, sun protection on the roof is necessary in order to avoid overheating in summer. The PV cells absorb 70 to 80% of the sun radiation. The space between the cells transmits enough diffused daylight to achieve a pleasant lighting level in the area. PV cells were used in this way at the Centre for Sustainability De Kleine Aarde in Boxtel (NL) [11] and the Brundtland Centre (DK). Using transparent PV modules in the Solar Office in Doxford (UK), has resulted in a similar contrast in the façade [12]. In order to increase the usage of daylight in the workplaces, transparent PV modules have been used instead of glass.

Of course, PV cells convert sunlight into electricity (with typical efficiencies of 6–15%) with the remainder of the solar energy being converted into heat. At the project "Haus der Zukunft" in Linz (AT), this residual heat is also used to warm the home [13]. An air cavity has been created underneath the PV modules, through which warm air (heated by PV modules) is exhausted. The hybrid collector provides warm air to the heating system in the home, which in this case, makes it a cost-effective use of the collector.

At the Netherlands Energy Research Foundation (ECN) in Petten (NL), Building 42 has a conservatory with 43 kWp BP solar roof-integrated transparent laminates that reduce light and sun transmission by around 70% as compared to glass. The conservatory therefore acts as a big parasol over the offices, protecting them from the sun while still providing enough daylight (Figure 22.5) [14].

Facades are basically constructed using *in situ* bricklaying or concrete constructions, prefab elements or structural metal facades that are mounted in place. Concrete constructions form the structural layer and are covered with insulation and a protective cladding [15]. This cladding can be wood, metal sheets, panels, glass or PV modules. For luxury office buildings, which often have expensive cladding, cladding with PV modules is not more expensive than other commonly used materials, for example, natural stone

Figure 22.5 Interior view of the conservatory with integrated 43 kWp transparent BP solar modules in ECN Building 42 in Petten (NL). Reproduced with permission by BEAR Architecten T. Reijenga

and expensive special glass. This cladding costs around \$1000/m^2, which is comparable to the cost of the PV module today.

Structural glazing or structural facades are constructed using highly developed profile systems, which can be filled with all types of sheeting, such as glass or frameless PV modules. Facades are very suitable for all types of sunshades, louvers and canopies [16]. There is a logical combination between shading a building in summer and producing electricity at the same time. Architects recognize this and many examples of PV shading systems can be seen around the world (Figure 22.6). A canopy (entrance protection) on the sunny side of a building is a good place for BIPV systems (Figure 22.7) thus providing shade, protection from rain, as well as electricity.

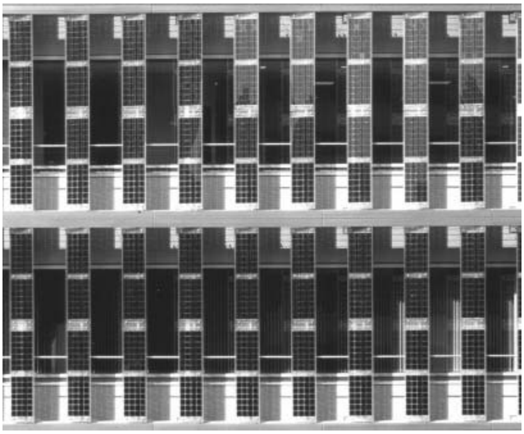

Figure 22.6 Solar shading (PV modules as part of a vertical louver system) on the west façade of the SBIC office building in Tokyo (JA). The transparent vertical louvers, with a total capacity of 20.1 kWp, were manufactured by Atlantis Switzerland. Reproduced with permission by Jiro Ono

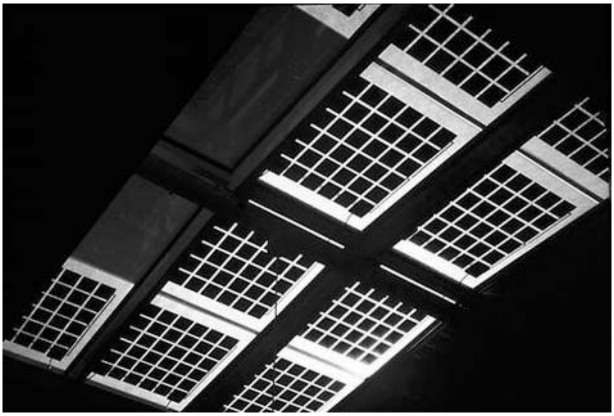

Figure 22.7 This system is the 1.25 kWp canopy with Atlantis transparent modules at the Thoreau Center in San Francisco, CA (USA). The canopy protects the entrance against the rain and wind but daylight is still allowed through via the transparent modules. Reproduced from Eiffert P, Kiss G, *Building-Integrated Photovoltaic Designs for Commercial and Institutional Structures – A Sourcebook for Architects*, 7–10, NREL, Golden, CO (2000) with permission by NREL USA [17]

22.2.2 PV as Part of "Green Design"

The government's role in promoting and supporting sustainable energy (PV systems) strongly influences the extent to which these systems are used in buildings. In countries with less government intervention, the power companies play a bigger role. Even without financial support, the government can encourage sustainable energy, for example, by demanding better performance for buildings. By introducing certain performance goals, sustainable energy and solar energy PV systems might be considered.

There is a growing interest in "green" products such as organic food, organic fibers as well as green buildings. Insurance companies and financial markets are becoming aware of "green" financing, which requires a different design approach from architects. "Green" design is the basic reason for integrating PV systems into buildings.

22.2.3 PV Integrated as Roofing Louvres, Facades and Shading

For architects, the application of PV systems must be part of a whole (holistic) approach. A high-quality PV system can provide a substantial part of the building's energy needs if the building has been designed in the right way. In general, the energy consumption of buildings needs to be cut down by at least 50% compared to a typical but inefficiently designed building.

In a holistic approach, integrating a PV system not only means replacing a building material but also aesthetically integrating it into the design. The integration also takes over other functions of the building's skin. Mounted on a sloped roof, profile systems mean that PV modules can be part of the watertight skin. The system can also be mounted above an impermeable roof foil, thereby protecting the foil against UV light and direct sun. This extends the life span of the foil. This kind of system is also available for flat roofs. The Powerlight Company from Berkeley, CA (USA) introduced a PV system into the market that is glued on expanded polystyreen (XPS) insulation material. This type of warm roof construction (construction on the warm side of the insulation) system is very well suited to renovating large flat roofs (Figure 22.8).

The designer may well use building elements such as canopies and shading systems to integrate PV systems, but will need to look in detail at shading and PV technology to understand the details of how to design this PV integration. One of the first things that the designer will discover is the fact that an efficient PV system is not automatically a good shading system. In general, a PV system on louvres will need a certain mutual distance between the louvers to prevent shading of the cells, which may let too much sun through at a lower sun angle in spring and fall (Figure 22.9).

Figure 22.8 Powerguard flat-roof PV system including thermal insulation at the Coastguard building in Boston, MA (USA). The 3 kWp system has a special wind-tunnel-tested profile at the edge to keep the system on the roof in heavy winds. Adapted from Eiffert P, Kiss G, *Building-Integrated Photovoltaic Designs for Commercial and Institutional Structures – A Sourcebook for Architects*, 42–44, NREL, Golden, CO (2000). Reproduced with permission by NREL USA [18]

Figure 22.9 Colt shading system that is optimized for sun control. The distance between the louvers with PV modules cause shading on 50% of the PV cells; 47 kWp PV system at Stadtwerke in Winterthur (CH). Reproduced with permission by BEAR Architecten T. Reijenga

Heat load and daylight control systems can be combined with the integration of PV systems. Moreover, when the designer studies these aspects in detail, he or she will discover that PV systems can also be part of the thermal envelope or thermal system (Figure 22.10) [19]. Another example is the refurbishment of Building 31 in Petten (NL) [20]. In this project, the PV system is integrated into a louver system that supports the 35 kWp Shell Solar modules, to keep out the summer heat and give less glare, and improve daylight conditions inside. To prevent shading of the modules by the upper louver, the dimensions of the louvers have to be almost twice the size of the modules (Figure 22.11) (Diagram 1) [21].

Orientation is a major design issue for (green) buildings. The heat load of a building, the need for shading and the design of facades all depend on the orientation.

Figure 22.10 Daylight control at the Kaiser fashion house in Freiburg (D). This 4 kWp PV system on louvers is mounted in front of the glass façade and prevents glare inside. The PV louvers are in the center of the figure. Reproduced with permission by BEAR Architecten T. Reijenga

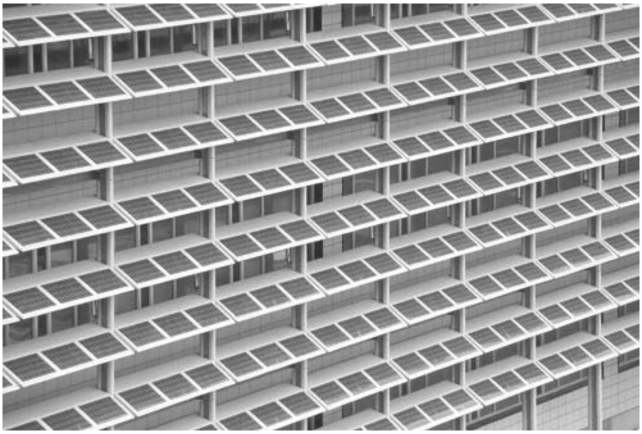

Figure 22.11 South façade of ECN Building 31 in Petten (NL). The shading structure supports the 35 kWp Shell Solar modules. Reproduced with permission by BEAR Architecten T. Reijenga

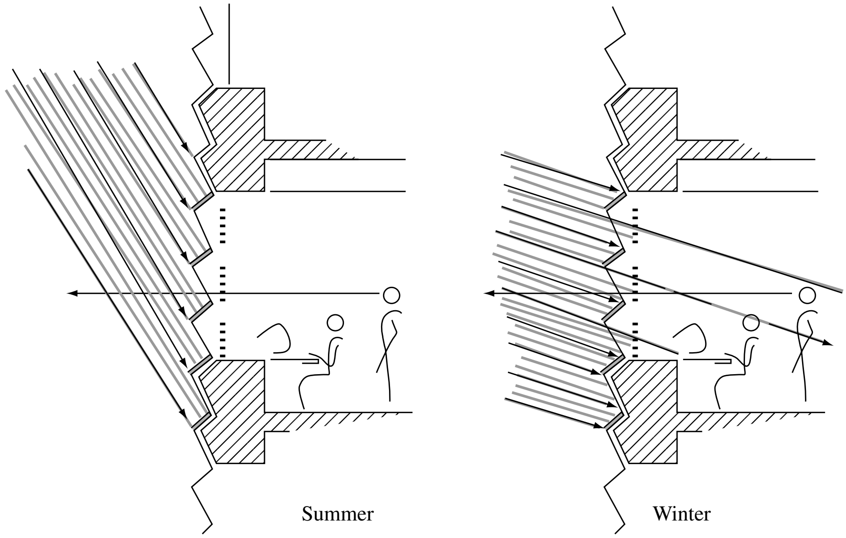

Diagram 1 Shading system with high angle (summer) and low angle (winter). In a fixed position designed for high angle of summer sun the system will be inefficient for the winter period. Reproduced with permission by BEAR Architecten, NL

Orientation is also important for PV systems. Facade systems might be suitable in certain countries, especially at a northern (above 50°N) or a southern (below 50°S) latitude. When shading of the facade cannot be prevented, and for the countries in between these latitudes, sloped surfaces facing the sun or even horizontal surfaces might be more suitable. The designer's final choice will be based on orientation, amount of total annual (sun)light on the PV module, shading from surrounding buildings and the aesthetics of the design. An important issue for the designer is to appreciate the blue, gray or black cells and to become familiar with finding integration opportunities in the first draft design. Ideally, a PV system should not be added to a building but designed as part of the building.

22.2.4 Well-integrated Systems

How can we discuss whether a BIPV system is well integrated? [22] A group of architects within the IEA PVPS (PV Power Systems) Task 7 workgroup discussed this subject and came up with several criteria for judging the aesthetic qualities of BIPV projects [23].

In order to decide which BIPV systems are of a high quality, we need to distinguish between the following:

- technical quality of the BIPV system, that is, the technical aspects of PV, cables and inverters,
- building quality of the BIPV system. Here we look for the quality of the system as a building element (part of the roof or the façade that is replaced by modules). The module and its integration must meet typical building standards, such as an impermeable layer or a structure strong enough to withstand wind or snow loads,

- aesthetic quality of the BIPV system. This is the least scientific and most subjective part of judging BIPV systems. But the reality is that architecturally elegant, well-integrated systems will increase market acceptance.

Both the technical and building qualities of the PV system have been considered as preconditions. All installations in a building must function correctly.

Aesthetic quality is not a precondition. Although the discussion of architectural values is very broad, high-quality architecture or poor architecture is generally recognizable.

The criteria formulated by the IEA PVPS Task 7 workgroup for evaluating the aesthetic quality of building-integrated PV systems are [24, 25]

- natural integration,
- designs that are architecturally pleasing,
- good composition of colors and materials,
- dimensions that fit the gridula,[1] harmony, composition,
- PV systems that match the context of the building,
- well-engineered design,
- use of innovative design.

These architectural criteria need to be explained particularly to nonarchitects and manufacturers developing photovoltaic systems for integration into roofs and façades, who often believe that their systems fit perfectly. Some architectural journals,[2] however, have criticized PV projects in, for example, the 250 kWp project in Sloten, Amsterdam (NL) [26] and the 1.3 MWp project in Nieuwland, Amersfoort (NL) [27]. The average architect is not yet convinced of the "beauty" of a PV system on his building. All the more reason this book should show appealing examples and critically judge PV products.

The Lafarge Braas PV 700 roof tile system is a good example of how manufacturers look at their product. This system can be placed invisibly in between the flat Lafarge Stonewold tiles (Figure 22.12) [28].

However, in product advertisements, the manufacturer has chosen tiles with contrasting colors instead of harmonious colors, thus ignoring the fact that integration, in most situations, should be discreet. After commercial introduction, the system was prepared for use with a standard roofing tile. This corrugated tile is an even bigger contrast to the flat PV elements. Technically speaking, this high-quality product has been integrated. Aesthetically, however, the product has not been integrated because of the contrast. Therefore, the architect, building inspectors and clients might reject a PV system incorporating this product.

Explanation of the criteria

- *Natural integration*: This means that the PV system seems to form a logical part of the building (Figure 22.13). The system adds the finishing touch to the building. The

[1] Gridula is not a common word outside architectural vocabulary. It means the grid that is used for the design that is a (sometimes hidden) part of the building.
[2] Archis February 1998.

Figure 22.12 This sustainable WWF (World Wildlife Fund) project in Harderwijk (NL) has a roof with a thermal solar collector on top and a 460 Wp PV 700 system underneath. The PV 700 system fits almost invisibly in between the tiles. Reproduced with permission by BEAR Architecten T. Reijenga

Figure 22.13 A naturally integrated PV system that is clearly part of the building. This system is located in Poitiers (FR). Reproduced with permission by ECN J. Beurskens

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.

- *Architecturally pleasing*: The design has to be architecturally pleasing (Figure 22.14). The building should look attractive and the PV system should noticeably improve the design. This is a very subjective issue, but there is no doubt that people find some buildings more pleasing than others.
- *Good composition of colors and materials*: The color and texture of the PV system should be consistent with the other materials (Figure 22.15).
- *Fit the gridula, harmony, and composition*: The dimensions of the PV system should match the dimensions of the building (Figure 22.16). This will determine the dimensions

Figure 22.14 Corridor in the Centre for Sustainability De Kleine Aarde in Boxtel (NL). The space is unheated and naturally ventilated. The 6.7 kWp PV system with transparent modules has a double function and reduces the heat load by around 70%. Reproduced from Reijenga T, Böttger W, *Proc. 2nd WC Photovoltaic Solar Energy Conversion*, 2748–2751 (1998) with permission by NOVEM, R Schropp [11]

Figure 22.15 The 80.5 kWp Atlantis Sunslates on the roof of the historic horse stables in Bern (CH). The color and texture matches so well that this PV system was allowed on a protected historic building. Reproduced with permission by Atlantis Solar Systems Ltd

of the modules and the building grid lines used (grid = modular system of lines and dimensions used to structure the building).

- *Matching the context of the building*: The entire appearance of the building should be consistent with the PV system used (Figure 22.17). 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.
- *Well engineered*: This does not concern the waterproofing or reliability of the construction. However, it does concern the elegance of the details (Figure 22.18). Did the

Figure 22.16 The cube at the Discovery Science Center in Santa Ana, Los Angeles, CA (USA). The 20 kWp PV system fits the gridula of this huge structure and there is harmony between the PV modules and the structure behind. Some 494 Thin-film Millienna photovoltaic modules from BP Solar were used on the solar cube. Reproduced from Eiffert P, Kiss G, *Building-Integrated Photovoltaic Designs for Commercial and Institutional Structures – A Sourcebook for Architects*, 48, 49, NREL, Golden, CO (2000) with permission by BEAR Architecten T. Reijenga [29]

Figure 22.17 The 180 kWp Sofrel flat-roof system on the UBS Bank near Lugano (CH) matches the context of the roof, which fits between different installations, high-tech chimneys and the tight rhythm of the flat-roof PV system on the roof. Here the BIPV is mainly aesthetically and not physically integrated. Reproduced from Maycock P *et al.*, *Building with Photovoltaics*, 78–81, Ten Hagen & Stam, Den Haag (1995) with permisson by UBS Switzerland [10]

designers pay attention to detail? Has the amount of material been minimized? These considerations will determine the influence of the working details.

- *Innovative design*: PV systems have been used in many ways but there are still countless new ways to be developed. This is all the more reason to consider this criterion as well.

Figure 22.18 The Schüco façade in the Solar office in Doxford, Sunderland (UK) is well engineered. Reproduced with permission by BEAR Architecten T. Reijenga

22.2.5 Integration of PV Modules in Architecture

The integration of PV systems in architecture can be divided into five categories:

1. Applied invisibly
2. Added to the design
3. Adding to the architectural image
4. Determining architectural image
5. Leading to 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 invisibly. A visible PV system is not always appropriate, especially in renovation projects with historic architectural styles. The challenge for architects, however, is to integrate PV modules into buildings properly. PV modules are new building materials that offer new designing options. Applying PV modules in architecture should therefore lead to new designs. In some of the selected projects, the design was based on this principle.

1. *Applied invisibly*: The PV system has been incorporated invisibly (and is therefore not architecturally 'disturbing') (Figure 22.19). The PV system harmonizes with the total project. An example is the Maryland project in the USA (Figure 22.20), where the architect tried to integrate PV modules into the design invisibly. This solution was chosen because the entire project concerned historic architecture. A modern high-tech PV module look would not be appropriate for this architectural style.
2. *Added to the design*: The PV system is added to the design (Figure 22.21). Building integration is not really used here, but this does not necessarily mean that architectural

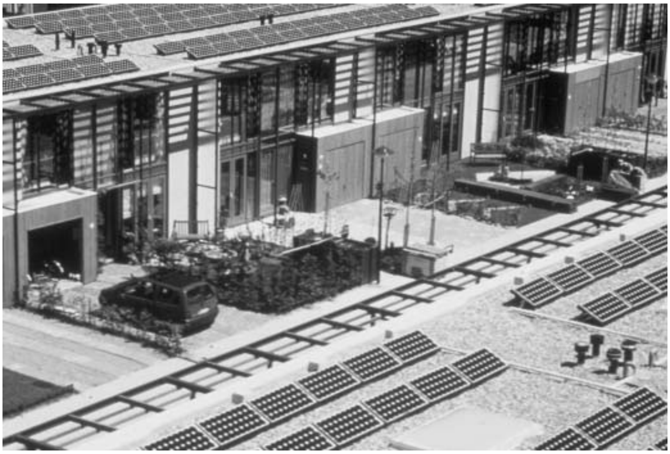

Figure 22.19 Modern style houses in the 1.3 MW project in Amersfoort (NL). The architect thought that the modules did not blend in with the design. He chose an "invisible" solution with a flat-roof system. The PV system is not visible from the surrounding streets. Reproduced with permission by REMU J. van IJken

Figure 22.20 Houses at the National Research Home Park in Bowie, MA (USA) in historic style. The roofs are Unisolar standing-seam roofs with thin film (amorphous silicon). Reproduced with permission by NREL USA

integration is also lacking. The "added" PV system is not always visible either (Figure 22.22).

3. *The PV system adds to the architectural image*: The PV system has been integrated beautifully into the total design of the building, without changing the project's image (Figure 22.23). In other words, the contextual integration is very good (Figure 22.24).

Figure 22.21 The IES building in Madrid (E) has a 6.6 kWp PV system that was added shortly after the building was finished. The modules are mounted on the façade above the windows and keep out the sun. Reproduced with permission by BEAR Architecten T. Reijenga

Figure 22.22 These houses in Amersfoort Nieuwland (NL) have a roof with a white foil on top. The architect chose a color contrasting with the color of the modules to show that the PV system is an addition to his design. Reproduced with permission by REMU J. van IJken

4. *The PV system determines the architectural image*: The PV system has been integrated into the design in a remarkable and beautiful way and plays an important role in the total image of the building (Figures 22.25 and 22.26).
5. *PV system leads to new architectural concepts*: Using PV modules, possibly in combination with other types of solar energy, leads to new designs (Figure 22.27) and new architecture (Figure 22.28). The integration of PV modules was considered on a conceptual level, which gives the project extra value.

Figure 22.23 The architect integrated the (in total 49 kWp) PV modules into the facades above the windows and produced a combination with the roller blinds. The EMPA office building is located in Sankt Gallen (CH). Reproduced with permission by Electrowatt Eng. Services

Figure 22.24 In this office building in Gouda (NL), the 6.2 kWp PV system is mounted on top of the façade as a canopy that protects the wall. The architect's intention was to show the PV system to his clients when they visit the office. Reproduced with permission by BEAR Architecten T. Reijenga

22.2.6 Brundtland Centre, Toftlund (DK) – a Case Study

The Brundtland Centre in Toftlund opened in 1995, was developed as an education and demonstration center for Denmark [31]. It is part of the "Brundtlandby Project", which designated certain towns, such as Toftlund, to put into practice the goals of low energy consumption and environmental impact, as proposed by the Brundtland Report. The Brundtland Centre was built to exhibit and employ the concept of energy-efficient building strategies combined with well-implemented architectural design. Throughout the

Figure 22.25 The dwellings at the 5 MW project in the HAL district of Langedijk (NL) have a large PV roof without any perforations. This strengthens the architectural expression of the roof design. Each roof includes a 5.1 kWp BP Solarex PV system. Reproduced with permission by BEAR Architecten M. van Kerckhoven

Figure 22.26 The canteen at the IMEC in Leuven (B) has an entrance with attractive-looking transparent modules in the roof. Reproduced with permission by IMEC

design process, priority was given to strategies that could be achieved through the design of the building itself – its form, orientation and envelope design – rather than "high-tech" strategies. Where the use of "active systems" was necessary, the design team aimed to develop more energy-efficient ways of operating these technologies.

Early consideration of PV within the design process has resulted in an aesthetically and energetically well-integrated PV system within the architectural design (Figure 22.29). Two types of PV systems are used in the building envelope. A PV array is integrated

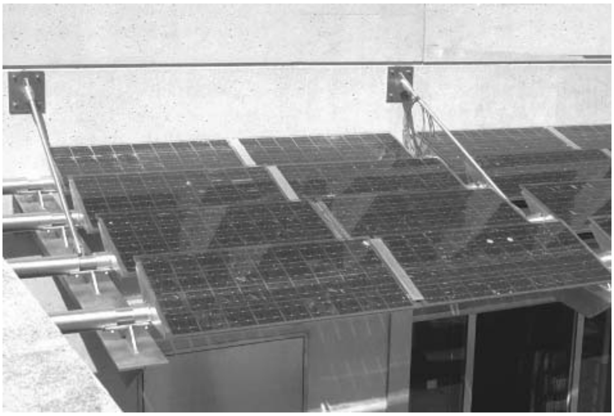

Figure 22.27 This shopping mall in Lausanne (CH), includes a louver system with transparent modules mounted above the shop windows, which results in less reflection of sunlight in the windows, making it easier to look into the shops. Reproduced with permission by BEAR Architecten T. Reijenga

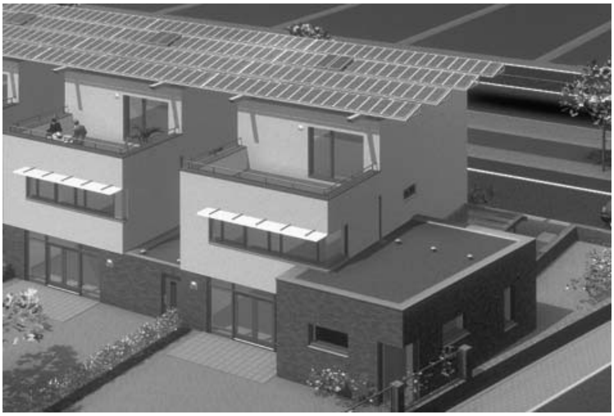

Figure 22.28 This zero-energy project in Etten-Leur (NL) combines different sustainable energy techniques. Each house has a roof structure with 6.2 kWp BP Solar PV modules. The aesthetic integration of the PV system is a completely new concept in housing. Reproduced from Reijenga T, "Energy-Efficient And Zero-Energy Building in the Netherlands", *Proc. International Workshop on Energy Efficiency in Buildings in China for the 21st Century*, CBEEA (Beijing, December 2000) with permission by BEAR Architecten M. van de Laan [30]

into the roof of the atrium – a central space connecting the adjacent two-storey building sections. Other PV modules are mounted on the southeast façade of the office section (Figure 2.30).

The atrium roof, incorporating the transparent PV modules, stretches out above the entrance of the building, creating a large canopy. Thus, the PV system mounted on the atrium roof is visible from the inside of the atrium as well as from the outside of the building. Mounting the PV system on the roof had a great impact on the architectural expression, the building layout and internal atmosphere of the center (Figure 22.31).

Figure 22.29 Overview of the Brundtland Centre in Toftlund (DK). The glass roof on top of the atrium in the middle of the building has a saw-tooth roof with integrated 9.8 kWp transparent PV modules. Reproduced with permission by BEAR Architecten T. Reijenga

Figure 22.30 PV modules above the windows on the southeast facade. A total of 6 kWp is integrated in the facade. Reproduced with permission by BEAR Architecten T. Reijenga

To achieve the optimum orientation and tilt angle of the PV array (south/60°), the atrium roof has been constructed in a saw-tooth shape that runs diagonally across the space. The steel truss roof, combined with the alternating pattern of dark round cells against transparent glazing, gives the atrium a high-tech atmosphere. Special attention has been paid to provide soft diffused quality of daylight in the interior of the atrium. A thin diffusing glass fabric is integrated into the modules so that sharp edges from the circular solar cells are softened.

In energy terms, the integrated PV system in the atrium roof was designed not only to produce electricity but also to provide shading to prevent the atrium from overheating. The transparent modules allow 20% of the available daylight to enter the atrium. The concrete floors and facades accumulate the heat surplus during the day. At night, the atrium is cooled by natural ventilation, while the mechanically assisted ventilation is used to ventilate the adjacent rooms. Automatic controls stop the ventilation when a sufficiently low temperature has been reached.

Figure 22.31 Atrium roof of the Brundtland Centre building from the inside. Because the saw-tooth roof casts a shadow on the modules, some of the cells are fake. This solution achieves a more elegant look from the inside. Reproduced with permission by BEAR Architecten T. Reijenga

22.3 BIPV BASICS

22.3.1 Categories and Type of Buildings

Building-integrated PV systems can be divided into different categories according to

1. cell and module type,
2. architectural integration,
3. type of building,
4. mounting technology, and
5. the function of the integration, and possible additional building and architectural functions of the PV system.

It is important that architects know all these categories and their possibilities. The design process consists of translating the brief (program made by the client) into spaces and enclosures, as well as combining functions and materials into constructions. This process is mainly based on experience and knowledge of constructions and materials. New applications based on existing knowledge or techniques are very important in the creative process. New inventions play a minor role in the process.

22.3.1.1 Categories of cells and modules

There is a wide range of cells and modules in the market. There are various types of cell material, types of modules, framed or nonframed laminates, colors of the cells and colors of back sheets and frames; all provide a wide range of possible surfaces [32]. This is a very basic knowledge for architects. Architects will design BIPV systems with a certain image in mind. The choice of monocrystalline or polycrystalline cells will depend on color and not on efficiency [33].

22.3.1.2 *Categories of integration*

BIPV systems in projects can be divided according to the location of the application: roof systems, facade systems, glass construction (conservatory/atrium) systems and building components such as shading and canopy systems. The main mounting locations are the roof and the façade. There are also many creative solutions available in designing how PV systems can be integrated. All these solutions are grouped as building components.

22.3.1.3 *Types of buildings*

Different buildings obviously have very different functions, for example, apartments and family houses, public buildings, commercial and industrial buildings and nonoccupied building structures. These can either be newly constructed or renovated buildings [34]. Nonoccupied building structures include shelters (bus stops, canopies, parking structures), kiosks (newsstands, gazebos, pavilions, phone booths), public toilet buildings, car parks, streetlights, parking meters, screens and barriers (fences, noise barriers), road signs and commercial billboards.

All types of building or nonoccupied building structures are a potential location for BIPV systems.

The various commercially available mounting applications can be grouped into 10 types, and can be found on the on-line PV database (*www.pvdatabase.com*).

Location on a building:	Building component(s):	Manufacturers such as:
Sloped roof	Tiles and shingles	LaFarge Braas (Figure 22.12), Atlantis Sunslates [35] (Figure 22.15), Japanese tiles (Figure 22.32), UnisolarStanding Seam panels [36] (Figure 22.20).
	Nonintegrated profiles	BP Sunflower (Figure 22.33), Econergy InterSole [37], Alutec profiles (Figure 22.34)
	Integrated profiles	BOAL/Shell Solar profile system (Figure 22.3), Solrif Solar profile system [38] (Figure 22.35)
Flat roof	Roofing element	Powerlight Powerguard® (Figure 22.8), Alwitra Evalon® roofing foil (Figure 22.36)
	Integrated profiles	Schüco profile system (Figure 22.37)
	Independent support structure	Econergy ConSole [39] (Figure 22.19), Solgreen (Figure 22.38), Sofrel [40] (Figure 22.17), Sobac [41]
Facade	Integrated profiles	Schüco façade profile system (Figure 22.39)
	Cladding system	BP Solface [42] system (Figure 22.40)
	Louvers or sun blinds	ADO louver system (Figure 22.41), Colt Shadovoltaic louver system (Figure 22.9)
	Canopy	Donjon canopy system (Figure 22.42)

Figure 22.32 Prefabricated Japanese tilelike roof panel method with CdTe cells in Nie-ken (JA). Capacity of the system is 1.3 kWp. Reproduced with permission by MSK Corporation

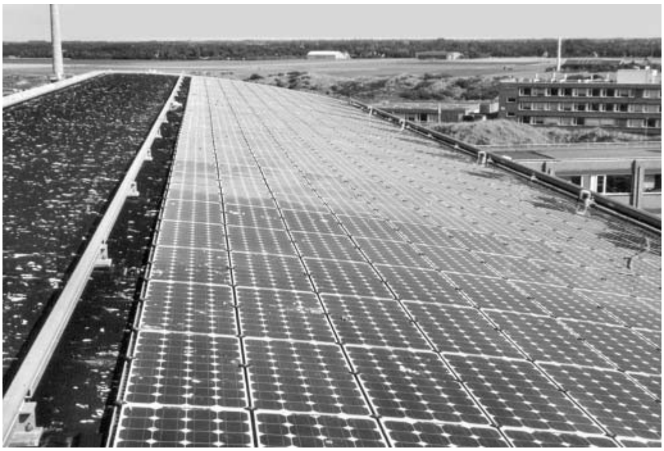

Figure 22.33 BP Sunflower system at the bent roof at ECN building 31, Petten (NL). Capacity 35 kWp. Reproduced with permission by BEAR Architecten H. Lieverse

22.3.1.4 Function of the integration

In addition to generating electricity, PV modules are also used as an integral part of the external skin (roof or façade), as sun protection (Figure 22.43) or as a daylight transmitter. Designing double functions and then integrating PV modules into buildings results in cost reductions on the investment in the building. Several buildings have been built that demonstrate PV systems as part of a passive cooling strategy [14].

The advantages in this specific case are

- the PV modules replace building elements,
- the PV modules are very well ventilated at the back,

Figure 22.34 Alutec profile system in a new roof in Langedijk HAL (NL). Capacity of the system is 53 kWp and the project is part of the 5 MW BIPV project. Reproduced with permission by BEAR Architecten M. van Kerckhoven

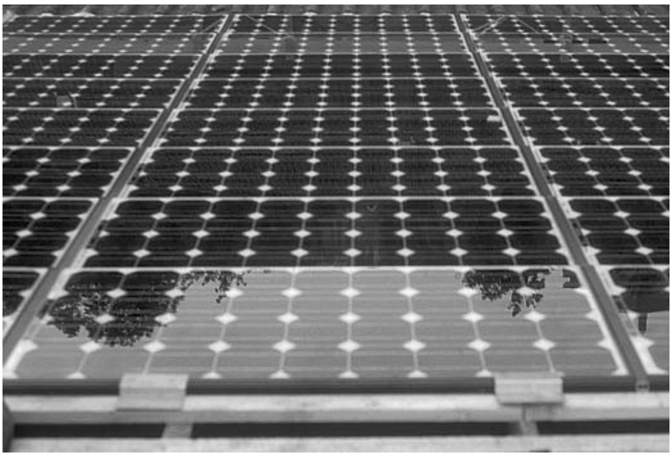

Figure 22.35 Solrif Solar profile system in a roof renovation in Zürich (CH). Capacity of the system is 53 kWp. Reproduced with permission by BEAR Architecten T. Reijenga

- a separate mounting construction is not necessary, and
- the air-conditioning system is eliminated.

22.3.2 Cells and Modules

The PV modules and mounting system are the elements of a PV system that can determine the image of a building. A PV system, particularly the cell material, framing materials, soldering, shape of the modules and the color of cells and back sheets, all influence the image of a building. For architects and designers, these aspects are more important than

Figure 22.36 Alwitra Evalon® roofing foil with amorphous silicon cells. Reproduced with permission by O.Ö. Energiesparverband

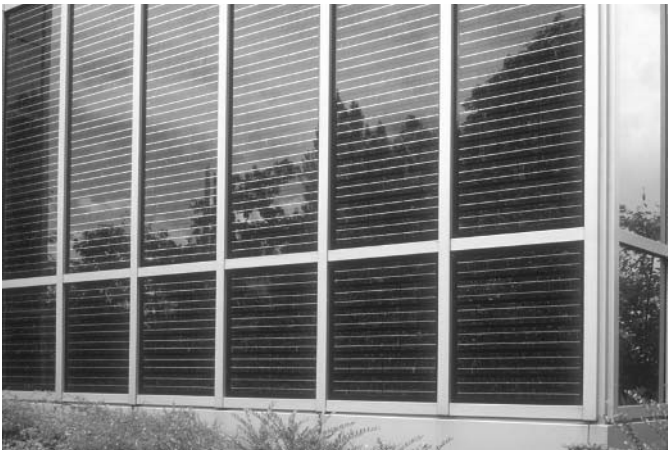

Figure 22.37 Schüco 1.9 kWp roof profile system with transparent modules in the Energy Forum Center in Bad Oeyenhausen (D). This mounting system can also be used in (difficult) horizontal situations. Reproduced with permission by BEAR Architecten T. Reijenga

the electrical efficiency of a system. Typical efficiencies of today's commercially available solar modules are shown in Table 22.1.

22.3.2.1 Solar cell materials

There are several types of solar cell materials: monocrystalline (single crystal) silicon, polycrystalline silicon (both discussed in Chapters 6 and 7), amorphous silicon (Chapter 12), copper indium gallium diselenide ($CuInGaSe_2$) (Chapter 13), and cadmium

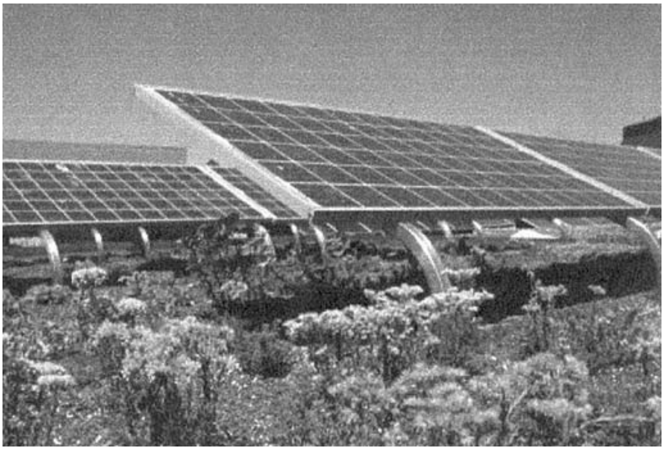

Figure 22.38 Solgreen flat-roof system for green roofs demonstrated on a roof in Switzerland. Reproduced with permission by SOLSTIS

Figure 22.39 Schüco façade profile system in the Doxford building (UK). See also caption at Figures 22.4 and 22.18. Reproduced with permission by BEAR Architecten T. Reijenga

telluride (CdTe) (Chapter 14). Their characteristics that affect their implementation in BIPV applications are briefly presented here.

Monocrystalline Si cells are initially grown as long cylinders, then sliced into thin discs called wafers (~300 μm thick). Initially round, the wafers often have their edges cut to create a nearly square wafer with slightly rounded corners. This increases their packing density on the module. Typical wafers are presently 10×10 or 12.5×12.5 cm^2 but will be increasing as technology develops. Monocrystalline cells have a very uniform appearance. Their color can be varied (see below) but are typically either dark blue or black since this gives the highest efficiency. (The color of the cell is determined by

Figure 22.40 BP Solface vertical wall system at the Demosite in Lausanne (CH). Reproduced with permission by EPFL-LESO-PB

Figure 22.41 ADO louver system with integrated transparent PV modules at an apartment building in Amersfoort Nieuwland (NL). The automatic louvers can switch in two positions. The horizontal position at night (left on the figure) and tilted to the sun by day (right on the figure). Reproduced with permission by BEAR Architecten T. Reijenga

the wavelengths that are reflected. The darker the cell looks, the less light that is being reflected. Therefore darker means more absorption of sunlight by the solar cell.)

Polycrystalline silicon wafers are manufactured with a lower cost process than monocrystalline silicon wafers. They are cast in long square ingots. After slicing, polycrystalline wafers are already in the desired square shape. Compared to monocrystalline cells, polycrystalline cells also typically have a bluish color and are the same size, but are slightly less efficient and slightly of lower cost. The main difference between mono and poly wafers as might affect their application for BIPV is their visual

Figure 22.42 Canopy at the eaves of a roof. 6.2 kWp PV system at an office building in Gouda (NL). Reproduced with permission by BEAR Architecten T. Reijenga

Figure 22.43 This building, at ECN in Petten (NL) has a 43 kWp PV system integrated into the conservatory roof. The conservatory acts as a parasol in front of the offices, thus eliminating the need for air-conditioning in a moderate climate. The building on the right side has a PV shading system (see caption on Figure 22.11). Reproduced with permission by BEAR Architecten T. Reijenga

appearance: monocrystalline cells are uniform while polycrystalline cells have hundreds of reflective facets, of sizes 0.1–1 cm. Each facet is a separate small crystalline region. Both mono and poly cells have metal grids on the front in a rectangular pattern to collect the electricity and to connect to the next cell. These grids are typically not visible from beyond a few meters away.

Amorphous silicon cells (a-Si) are composed of silicon atoms that are in a thin (~1 μm) layer and lack crystalline properties. They are commonly referred to as thin film Si PV technology. Amorphous silicon cells are deposited onto substrates like glass window

Table 22.1 Typical efficiencies for modules. These values are obtained under standard test conditions. Different orientation in BIPV applications may result in lower performance

Cell type	Typical efficiencies [%]
Monocrystalline silicon	12–15
Multicrystalline silicon	11–14
Amorphous silicon	6–8
Cadmium telluride	7–10
Copper indium gallium diselenide	8–12

plates or flexible rolls of stainless steel or plastic, giving a wide range of mechanical strength, weight, and flexibility. The substrate is not visible since it is behind the solar cell. The cells have a uniform typically black appearance. These cells have no grids. Flexible substrates are ideal for curved surfaces and rollable "fold-away" modules. Amorphous silicon modules have lower efficiency than mono or poly silicon (Table 22.1) but better performance at higher temperatures [43, Chapter 12] as often occurs in BIPV applications.

Other thin film PV materials presently include $CuInGaSe_2$ and CdTe. They have a uniform nearly black appearance, indistinguishable visually from amorphous Si modules. They also have lower efficiency compared to mono or poly silicon. $CuInGaSe_2$ cells can be deposited on flexible plastic or metal foils.

Semitransparent cells for BIPV can be manufactured in two ways. Mono silicon wafers can have a series of deep grooves on the front and back which are perpendicular to one another. Where they intersect, light will be transmitted through the holes. Polycrystalline silicon cells with 2% transmission have been reported [44] but higher values should be possible with larger holes. Another approach is to make very thin amorphous silicon layers on glass with transparent contacts so the entire module is semitransparent. However, the transmitted light will have an orange or red tint because the blue and green portion of the spectrum is absorbed in the silicon layers. Such modules could only be used in applications where this color of light was acceptable such as sun-roofs for automobiles. A better method is to selectively remove part of the amorphous silicon layer using laser ablation. Unfiltered white light transmission of 5–15% have been reported for laser scribed amorphous silicon in BIPV applications [43].

22.3.2.2 Module temperature

Module efficiency, therefore electricity produced, decreases as the temperature increases for mono and poly silicon cells but not for amorphous silicon cells. In many non-BIPV applications, modules are mounted on free-standing frames with ambient air on both sides, allowing for cooling on both sides. In contrast, some BIPV applications install the modules in close contact to building material like roofs or wall insulation. The lack of circulating air increases the module temperature. Relative losses of >5% are possible [45]. A good design criterion for mono or poly silicon applications is to allow as much cooling as possible by providing for air flow behind the module and minimizing effect of insulation. This is not an issue for amorphous silicon modules [45].

22.3.2.3 *Color of the cells and modules*

Solar cells are basically blue, dark blue or black after processing. Different colors are possible but these are not manufactured as standard. Some manufacturers sell tailor-made cells in special colors (e.g. gold, gray, green, red-orange and yellow). The cell color is varied by changing the thickness of various optical coatings on top of the cell, which changes their reflection. The blue color produces the highest efficiency solar cells. Current literature gives efficiencies for colored cells as 11.8% and 14.5% compared to optimized cell efficiency of 16.8% [46, 47], which corresponds to around 75% of the power of dark-blue cells [48].

Modules have several sections that can be colored. Besides the cells, the frame and the back sheet will also have a certain color. Older modules had natural aluminum frames and a white back sheet. The shape of the cell was very pronounced because of the contrasting color. However, modern modules have colors that are more in harmony: dark-blue cells with a dark back Tedlar® sheet and a dark-colored frame around the module, which produces a very uniform image. A roof or façade containing these uniform-colored modules will be seen as a single surface. The opposite effect is also possible by using modules in striking colors to attract attention and focus on the PV system.

22.3.2.4 *The architecture of modules*

Architects select modules based on their shape and composition possibilities. There is a big visual difference between framed and frameless modules.

Frameless modules look very similar to window glass. A surface with frameless modules with a "hidden" mounting system looks very uniform. The seams seem to be hidden and the individual module is hard to recognize. This smooth surface has a high aesthetic value.

Framed modules give a totally different effect. The frames can be heavy and therefore determine the total impression of the surface. The very visible frames divide the surface into modules and every individual module is very recognizable. This is not always the image envisaged by the architect.

To solve this problem, smaller frames in the same (dark or blue) color as the cells can be used and are less visible. The soldering between the cells is a small detail but is an important part of the image for very visible PV systems. In the older techniques the soldering was very visible and not very smooth. However, new techniques mean that the soldering is hidden better and new types of soldering, for example, ECN cells, can be expected in the future.

Modules vary significantly in size. Standard modules are less expensive than applications using tailor-made modules. However, almost every form, shape and dimension is possible with tailor-made modules. The glazing is available as single and double (insulating) glass. Thin-film modules allow greater freedom to select size and color than c-Si modules.

22.4 STEPS IN THE DESIGN PROCESS WITH PV

22.4.1 Urban Aspects

The aim of integrating PV systems into buildings is to reduce costs. To generate maximum power from building-integrated systems, certain urban and architectural aspects are important.

The main starting point is the maximum power that can be generated by a system. The primary hindrances can be the (partly) shadowing of a system by other buildings or objects, and the nonoptimum orientation relative to the sun. Reflection can also be a problem for the surrounding buildings.

22.4.1.1 Orientation and angle

The amount of irradiance depends on the latitude. The maximum irradiance corresponds to surfaces, tilted at an angle equal to about the latitude minus 10° (see Chapter 20 for calculations on solar irradiance). At 52° north good results ($>90\%$) can be achieved by orienting the modules between southeast and southwest, with system angles between 30° and 50° from the horizontal. Orientations between east and southeast, and between southwest and west, are fairly reasonable with system angles between 10° and 30° from horizontal. The irradiance will be reduced by around 15% of the maximum.

Flat-roof systems with very low angles (between 5° and 10°) can be a good solution for difficult orientations. The loss of irradiance will be between 5% (south) and 20% (north).

22.4.1.2 Distance between buildings

Shadowing is a critical issue for BIPV. In general, designs in which the PV modules are shaded for much of the year should be avoided. For low-rise areas, the problem is easy to solve. The distance between individual houses can be calculated. For mixed height neighborhoods, it will be more difficult. A high-rise apartment building in a low-rise neighborhood can cause a lot of unwanted shading.

The density of an area also has a lot of influence. In high-density areas (cities) the distances between buildings are often so small that there is significant shadowing throughout a large part of the year.

On a general note, it is worth mentioning that facade systems (vertical) are more sensitive to shading and need longer distances from other buildings than tilted systems (roofs). Horizontal systems have a lower irradiance, as previously mentioned, but will be the best solutions for avoiding shadow. Only neighborhoods with a mixture of low- and high-rise buildings might be unsuitable for horizontal systems.

22.4.1.3 Trees

Greening the area around buildings makes the area look very attractive and the microclimate more comfortable for the inhabitants.

The shadowing effect of trees is very important, as the trees will be very dense during the summer. Even during the winter, when trees lose their leaves, the branches give too much shade.

The aspect of growth is sometimes underestimated. Planning for the future growth of trees is very important and must be done carefully to avoid problems a few years after the building has been completed or the PV system has been installed.

Solutions can be to

- only plant trees on the north side of buildings,
- plant only small trees up to two stories high,
- prune trees annually to keep them small.

22.4.1.4 Zoning

In future, a special solar zoning will be needed in urban areas with PV systems. The borders of building areas can be clearly marked on three-dimensional maps to prevent future problems. The amount of sunlight can also be determined on these maps.

22.4.1.5 Reflection

Although not a major problem, under certain circumstances, reflection can occur. In low-rise buildings, there are no significant problems, but in mixed low- and high-rise areas residents in high-rise buildings may experience some annoying reflections if all the surrounding houses have (glass-covered) PV modules. The fact that there are certain distances between buildings (for shadowing) may eliminate most of the potential problems.

22.4.2 Practical Rules for Integration

There are a few important rules for integrating modules into buildings. These rules concern the functioning and maintenance of the system, for example:

1. shadow is not allowed on the module,
2. ventilation is required at the back of the modules (not as important for thin film a-Si),
3. make it easy to mount and remove a module,
4. ensure that the module stays clean or can be cleaned,
5. make easy electrical connections,
6. ensure that wiring is sun-proof and weather-proof.

1. As previously mentioned, even partial shadow on the modules will decrease the energy output. Profiled mounting constructions, in particular like awnings, can produce shadows along the edge of the adjacent module that will result in loss of efficiency.
2. Modules with crystalline cells have a higher output when the temperature is lower. With ventilation at the back of the module it is possible to keep the temperature low

and avoid a decreasing output. However, thin-film amorphous silicon reacts differently. The higher temperature does not influence the efficiency as much as crystalline silicon.[3]

3. Although the lifetime of modules is proven to be over 20 years, it is better to know how to remove a single module in the middle without removing the whole system. Electrical connections should also be "plug and play".[4] Easy electrical connections are needed for fast installation and for easy replacement of modules. Depending on the local safety regulations, precautionary measures should be taken, for example, using lifelines or moveable safety ladders.
4. The surface of the modules should be clean. Tilted modules will be cleaned by rain in most regions. Modules mounted at low angles can be treated with PV-Guard, a treatment that makes the surface smooth and makes cleaning with rain easier. In dry areas, cleaning should be part of the regular maintenance schedule.
5. Protect wiring against the weather. Rain is not the main problem, though all connections must be waterproof. Long-term influence from water should be avoided. Protection against sun and UV light is needed to ensure that the linesman of the wiring is not reduced. Depending on the area, wiring may also need to be protected from small gnawing animals.

22.4.3 Step-by-step Design

A PV system consists of a number of modules with solar cells, an inverter, batteries or, in most cases, a connection to the grid. A single house with a small installation can be connected through the existing electricity meter. The electricity that is produced will be used primarily in the house. Any surplus will be fed into the grid and the meter will spin backwards. However, not every utility company will allow this and in some cases a second meter is installed. This often happens with larger systems (more than 2 or 3 kWp). Larger systems or combined systems that are maintained by the utilities are connected directly to the grid.

22.4.3.1 Solar design

To design with photovoltaics the first set of questions are, "Why do I want to integrate PV into the building?" and "Is it for general energy supply, to make the building more independent, or to make a statement about the building's inhabitants?"

Large systems will be used for general energy supply. This means large surfaces that can be treated in an architectural way. Different types of modules, shapes, colors or textures can be used to design the look of the building.

The main issues for a more independent building are the efficiency of the system and the generated yearly output. The size of the PV system will depend on this and the designer has to allow for a certain number of modules. The designer will probably design

[3] See Chapter 12.

[4] "Plug and play" refers to very simple wiring and components that fit together like a computer and can easily be replaced.

the building around the integrated system, otherwise the system will be something that is connected, but not integrated, into the building.

22.4.3.2 Module placement and shadowing

The first step in the design process will be to look at the number of modules, their dimensions and the total dimensions of the system. All these aspects have to be integrated into the roof or facade. Shadowing of the modules is important. A module that is partly shaded will lose more efficiency than expected. If one row of cells in a module is covered or heavily shaded, this can block the output of the entire string.

Small objects that can cause shading, such as chimneys and fans, are less important. The shadow will move during the day and there maybe indirect light available. Some modules have integrated diodes that allow a short break when a row of cells is covered or shaded.

22.4.3.3 Space required for balance of systems and interconnections

Space is also required for the inverters. The modules have junction boxes at the back that are connected by cables to the inverters. For better efficiency, the best place for these inverters is near the modules. An AC cable has to be fed from the inverters into the grid via the meter.

Space is also required for a junction box at the back. Together with the ventilation required at the back of the module, this means a gap between 20- and 50-mm (depending on the size of the junction box) between the back of the module and the mounting surface that can be used for both functions.

Space for a second utility meter may be required near the first meter, unless a double meter can be used. Safety switches are required near the inverters in order to work on the PV system safely.

22.4.4 Design Process: Strategic Planning

A few procedural steps may be necessary to ensure that the PV system is successfully integrated into the design. A common rule is to integrate the PV system into the building process without disturbing that process.

Step 1: The first step is consultation with the authorities about local regulations, building permits and the electrical connection to the grid.

Step 2: The second step is to consult the utility company about the grid connection, electrical diagrams and the metering system.

Step 3: The third step is the internal meeting with all building partners. A kick-off meeting very early in the process may be useful, to discuss the entire integrated PV system with the building contractor, the roofing company, the electrician and the PV supplier.

There are many unique issues to resolve in installing BIPV. The main points in this meeting concern the responsibilities of each party in the building process. Who is responsible for the waterproofing of the roof – the roofing company or the PV installer? Who is responsible for electrical safety – the electrician or the PV installer? Who is responsible for safety on the site – the general contractor or the PV installer? All these aspects must be clearly defined and noted in advance.

Many PV suppliers offer turnkey contracts. This is easy for clients because they receive a complete working system for their money. However, the client is then responsible for the coordination between PV supplier and building contractor. Placing all responsibility with the building contractor means an extra surcharge of perhaps 10% on the cost of the PV system. A good solution is to make the building contractor (general contractor) responsible for the PV system and negotiate a special fee for coordination and use of equipment (scaffolds and crane) from the building contractor.

22.5 CONCLUSIONS

Building integration aims to reduce costs and minimize the requirement for land. To increase market acceptance it is important to show architecturally elegant, well-integrated systems. Moreover, building owners can show their environmental commitment with highly visible building-integrated PV systems.

This means that there is a large potential for BIPV in the built environment. The main factors for successful integration are suitable buildings [49], (i.e. suitable orientation and lack of shadow) and a reason for building integration. For newly constructed sustainable buildings, BIPV will be part of the energy strategy. However, for existing buildings there must be a valid reason for integrating PV systems. Building renovation, including the roof and façade, often provides an opportune time for selecting BIPV [50, 51].

The building or renovation process plays an important role in the success of BIPV. Can the building owner benefit from BIPV? If so, the owner will be willing to implement PV systems in the building plans. The architect or designer needs to have a good basic knowledge of BIPV and be able to integrate PV into the design. If architects do not understand the basics of PV, they will make mistakes that eventually have to be resolved during the installation process. The worst cases involve mistakes that cannot be resolved at the end of the building process and that result in a lower efficiency and quality of the PV system.

Is the utility company willing to cooperate? If not, the building owner will probably try to avoid difficulties in an already complex construction process.

The architect or designer should use all visible opportunities to integrate PV into the design in a highly aesthetic way. The important issues are the architectural function of a PV module (replacing other building elements) and the visible aspects of modules, such as the dimensions, mounting system, form and color of cells, back sheet and frames.

To recognize these aspects, criteria have been formulated for judging building integration of PV. These criteria are useful for manufacturers and technicians who are involved with building integration from the engineering and technical aspects of the building process.

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