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Use of Building Integrated Photovoltaic (BIPV)

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CHAPTER 3

Use of Building Integrated Photovoltaic (BIPV)

A Significant Step toward Green Buildings

Karunesh Kant, Amritanshu Shukla, and Atul Sharma

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3.1 INTRODUCTION

The projection of world energy demand will more than double by 2050 and triple by the end of the century. Incremental growth in existing energy networks will not be acceptable to supply this demand in a sustainable approach. Discovering sufficient supplies of clean energy for the future is one of society’s most daunting challenges. Sunlight provides by far the largest of all carbon-neutral energy sources. More energy from the Sun strikes the Earth in one hour ($4.3 \times 10^{20}$ J) than is consumed on the planet in a year ($4.1 \times 10^{20}$ J) [1]. Presently solar resource is exploited through solar electricity—$7.5$ billion industry growing at a rate of 35–40% per annum—and solar-derived fuel from biomass, which delivers the primary energy source for over 1 billion people. Worldwide, it’s well known that fossil fuels will gradually decline out of common use by humans. Due to that happening in the Earth’s atmosphere, it can be concluded that the environment is completely going to change as well as it will also force the planet to behave differently. The weather has been spiking to new highs
or dropping to new lows every year. The water level in the world has risen and yet the amount of fresh water, which is used for drinking purposes, has decreased. It is now common knowledge that lower energy necessity is a basic requirement to surviving in the modern era. Choosing to construct using eco-friendly and sustainable techniques helps society worldwide to save a significant amount of energy. Eco-friendly products not only have lower emissions and waste, but also they are constructed in a manner wherein less energy is used in their production thereby reducing their carbon emissions [2].

Not only do eco-friendly methods help save nature, they also help to save money. For example, using insulated glass helps regulate the temperature of a home by allowing in less sunlight on sunny days and more sunlight during the winter. Thus, less is spent on heating and cooling systems in order to keep the temperature maintained inside at the desired level. Due to the environmental crisis, the green building design revolves around a wide range of issues: habitat destruction, air pollution, stormwater run-off, resource use, and climate change. However, the ongoing consumption of energy to operate, condition, and light a building, as well as the energy embodied in ongoing protection, is the largest single source of environmental harm and resource expenditure due to buildings. Carbon emissions and energy security have signaled an even stronger focus on energy in green buildings, mainly as the energy utilization growth rate of countries such as China, India, Russia, and Brazil is boosted. Energy efficient appliances may help to reduce electricity costs significantly. Dropping the operational energy use and rising durability should be the prime concerns of architects who wish to design and build “green” buildings. The conclusion was made after spending a number of years looking at actual building energy consumption, reviewing countless computer simulations, and being involved in numerous green building charrettes. It had even been suggested that 80% of a green architect’s concern should be concentrated toward dropping energy expenditure during operation [3]. Figure 3.1 shows the global energy use by different sectors.

3.1.1 What Is Green Building?
A green building uses less energy, water, and other natural resources, creates less waste and greenhouse gases, and is healthy for people living or working inside as compared to a standard building. Another sense of a green structure is a clean environment, water, and healthy living. Building
green is not about a little more efficiency. It is about making buildings that optimize the local ecology, use of local materials, and most prominently they are built to cut power, water, and material necessities. Thus, if these things are kept in mind, then we will realize that our traditional architecture was in fact very green. The major intake of energy in buildings is throughout construction and later in lighting or air-conditioning systems. This consumption must be minimized. Possibly, this should be limited to about 80–100 watts per square meter [4].

3.1.2 Needs for Green Buildings
On a national and global scale, green building offers one of the most significant and exciting prospects for sustainable development. The design of our built environment influences us all, as well as our economies and environment. The benefits of green building are as follows.

3.1.2.1 Generating Sustainable Growth
The building sector is a driver of gross domestic product (GDP), which is a measure of a country’s economic performance, and green building offers an opportunity for increased output with decreased impact. Global construction output is projected to develop considerably by 2020, and with markets moving to greater resource productivity, policy makers have a vital role to play in ensuring European companies are at the forefront of the global green building market (Figure 3.2).
3.1.2.2 Creating Jobs

The construction industry employs billions of people, but it suffers from a skills shortfall. Getting talent and investment is one of the key challenges for employers. Green building gives a chance to people to become a part of the solution to worldwide challenges, to search new and exciting technologies, and to learn skills that will stay relevant.
3.1.2.3 Increasing Energy Security and Reducing Fuel Poverty

Many countries are importing oil and natural gas, which cost hundreds of billions of dollars per year. With greater energy efficiency across the world, buildings will help reduce this excessive cost, in addition to reducing the need for new expensive infrastructure. Individual energy security is also essential, and those whose fuel bills denote a significant portion of income are helped by enlarging efficiency too.

3.1.2.4 Improving the Delivery of Public Services

The power of a strong public sector leadership in green building is not just about helping lead the wider market. Green building can reduce the cost of running public buildings, grow the efficiency of service delivery, and help create the right environment to retain and foster the brightest talent.

3.1.2.5 Adding and Retaining Financial Value

Green buildings attract sales, rental premiums, and help in reducing capital expenses and diminish the risk of regulation requiring expensive alterations to buildings. Energy- and water-efficient buildings also save businesses’ and consumers’ money during the lifetime of the property.

The 10 best sustainable building locations range from Santa Monica, California, to Hyderabad, India, to Brisbane, Australia, and Budapest, Hungary, which shows that countries across the globe are embracing sustainability and the importance of becoming more energy efficient with new construction [5].

1. Robert Redford Building—The Robert Redford Building in Santa Monica, California is the headquarters of National Resources Defense Council. The building was named a LEED Version 2 Platinum green building rating. The building had the highest possible level of sustainable design.

2. Bank of America Tower—Bank of America Tower located at One Bryant Park in New York City received the U.S. Green Building Council’s LEED Core & Shell Platinum certification.

3. Council House 2—Council House 2 is an office building located in Melbourne, Australia that is occupied by the City of Melbourne council. In 2005, it turned into the first purpose-built office building in Australia to attain a maximum Six Green Star rating, certified by the Green Building Council of Australia.
4. Adam Joseph Lewis Center for Environmental Studies—Adam Joseph Lewis Center for Environmental Studies, on the campus of Oberlin College in Ohio, uses sustainable building practices to keep it energy-efficient and comfortable. The geothermal wells are used for heating and cooling of buildings, and for generation of electricity, a photovoltaic system was installed on the roof. For purifying and treatment of water, a water treatment system was also installed and treated water can be reused for toilets.

5. Sohrabji Godrej Green Business Centre—CII-Sohrabji Godrej Green Business Centre in Hyderabad, India offers advisory services to the industry in the areas of green buildings, water management, energy efficiency, renewable energy, environmental management, green business incubation, and climate change activities.

6. Santos Place—The building has a 6 Star Green Star in Brisbane, Australia, which opened in 2009. The property includes the latest tools in environmentally sustainable design and energy efficient initiatives to achieve a 5.5 star target NABERS energy rating.

7. Clinton Presidential Library—The William J. Clinton Presidential Library at 1200 President Clinton Ave, Little Rock, Arkansas has been chosen as one of the most energy proficient and environmentally friendly places to work in the United States by the U.S. Green Buildings Council under its Direction of Energy and Environmental Design Green Building Program.

8. K&H Bank Headquarters—The K&H Bank Headquarters in Budapest on the banks of the River Danube in Hungary is the country’s first LEED-NC rated building. The energy-saving design and technologies have resulted in a building that consumes around 22% less than a comparable conventional building, while providing optimum occupant comfort.

9. Park Hotel in Hyderabad—The Park Hotel in Hyderabad, India is a 270-room hotel notable for its remarkable facade of punched metallic, which helps as a sun and rain screen that guards the building’s high-performance windows. Daylighting, orientation, solar gain, and local climate were all taken into account during the design of the building to maximize light and minimize heat gain.
10. Marco Polo Tower—Marco Polo Tower (Figure 3.3), which is situated alongside the new Unilever headquarters and on the river Elbe, is a noticeable place in Hamburg, Germany. A vacuum collector on the roof of a tower with heat exchanger helps to turn the heat into the cooling system for the apartments. Innovative sound insulated air louvers, in the sleeping areas, make natural ventilation possible without increased noise pollution from outside.

FIGURE 3.3  Marco Polo Tower in Hamburg, Germany. (From http://www.energydigital.com/top10/2735/Top-10-sustainable-buildings-in-the-world.)
3.2 KEY APPROACHES FOR DEVELOPING GREEN BUILDINGS

The inefficient building design and the equipment associated with it have an adverse effect on health and comfort, due to unnecessary water and energy use. Optimum use of resources by improving the design of indoor environments for industrial, institutional, and commercial buildings can be done by engineers to help building owners, tenants, and other customers.

3.2.1 Building Design and Construction

In general, highly energy-efficient buildings use reduced amounts of natural resources and energy, are less expensive to run, and create fewer adverse ecological effects than conventional buildings. However, the process of designing, renovating, or constructing a high-performance building is different from the traditional design/build methods. The approach to whole building architectural design is well thought-out with its energetic design. Mechanical and electrical system’s capacity can be minimized by integrating passive solar technologies to help meet indoor space-conditioning requirements and electricity consumption. Building simulation software can guide decisions to achieve this strategy.

To increase energy efficiency of a building, a variety of measures are employed such as proper site selection and building orientation, which leads to greater heat gain by taking simple steps such as sealing air leaks around doors and windows. Renewable energy systems, active solar space heating systems, such as solar water preheaters, and solar electric (photovoltaic) panels used to offset some of a building’s electric usage through self-generation and net metering are also becoming more popular.

3.2.1.1 Passive Solar Design Techniques

In building design, construction, and planning, passive solar techniques are those that take advantage of solar heat and light to offset the need for gas or electric heating, air conditioning, and lighting. These kinds of techniques are different from active solar systems like photovoltaic solar panels, which transform solar rays into electricity for home use.

Common passive solar tactics include south-facing building orientations that absorb and store solar heat during the winter and deflect solar heat during the summer, and “daylighting,” or maximizing the use of windows and full-glass exterior walls, often covered with a heat-deflecting glaze, to allow natural lighting into the building’s interior.
work spaces, while minimizing the heat gain that might normally result.

3.2.1.2 Thermal Storage

Thermal storage may be implemented in individual building projects in numerous ways. Some of the most common strategies include strategic window placement and daylighting design, selection of appropriate glazing for windows and skylights, appropriate shading of glass to prevent undesirable heat gain, use of light-colored materials or paint for building envelopes and roofs, careful siting and orientation, and appropriate landscaping.

Passive solar heating systems in a building with south-facing orientation can be combined with solar heat-storing trombe walls or floors made with concrete, tile, brick, stone, or masonry that absorb solar heat, store it, and then slowly release the heat into the building. Due to the angle at which solar rays reach the Earth’s surface during winter, a south-facing building with a large overhang will be able to absorb the heat of the sun, lessening the need for energy-consuming heating systems. During summer months when solar rays arrive at a much higher angle, the overhang shades the building, eliminating much of the heat gain that would otherwise result and reducing air conditioning use.

According to the U.S. Department of Energy, energy cost reductions of 30–50% below national averages are possible with 45 cents to 75 cents per square foot annual savings in new office building designs if an optimum mix of energy conservation and thermal storage design strategies are applied (building “thermal”). However, the department noted that it is rarely feasible to meet 100% of a building heating or cooling load with passive solar, where an optimum design is based on minimizing life-cycle cost.

3.2.1.3 Cooling Strategies

During the summer months, air conditioning systems consume much electricity. Alternative passive cooling strategies, especially when used in conjunction with thermal storage techniques that prevent heat absorption, may reduce the need for heavy air conditioning. Such cooling techniques include the use of natural ventilation, ceiling fans, atria and stairwell towers, evaporative cooling systems for dry climates, dehumidification systems, and geothermal cooling and heat pump systems. These methods can effectively remove heat from the interior of a building without the use of energy-intensive conventional air conditioning systems.
3.2.1.4 Daylighting
Daylighting techniques involve the incorporation of natural daylight into the mix of a building’s interior illumination. When appropriately designed and joined with electric lighting, daylighting can propose significant energy savings by offsetting a portion of the electric lighting required. A side benefit of daylighting is that it also reduces the internal heat gain from electric lighting, thereby reducing required cooling capacity. Results of recent studies imply improved productivity and health in daylit schools and offices. Windows—the principal source of daylight—also provide visual relief, a visual portal to the world outside the building, time orientation, and a possible source of ventilation and emergency egress (U.S. Dept. of Energy, Building Daylighting). Other sources of daylight include light pipes with mirrored inner surfaces that bring natural light deep into a building interior, skylights, sky domes, and reflective devices and surfaces that spread daylight more evenly in occupied interior spaces.

3.2.1.5 High-Performance Insulation
A type of superinsulating material increasingly used for residential and light commercial buildings is structural insulated panels used in floors, walls, and roofs. The panels are manufactured by forming a sandwich of rigid foam plastic insulation between two panels of plywood. The panels generally cost about the same as building with wood-frame construction, but labor costs and job-site waste are reduced (structural).

In early 2007, the American Institute of Architects; the American Society of Heating, Refrigerating and Air Conditioning Engineers; Architecture 2030; the Illuminating Engineering Society of North America; and the U.S. Green Building Council, with the support of the U.S. Department of Energy, finalized an agreement of understanding establishing a common benchmark and the goal of net zero energy buildings. The ultimate goal is carbon-neutral buildings by 2030. To reach that goal, the alliance partners agreed to define the baseline for their common target goals.

3.2.2 Methods to Decrease Energy Use by Building Operating Systems
Most large, multistory buildings employ sophisticated, computer-based building control systems that integrate key subsystems such as lighting, security, fire protection, heating and air conditioning, occupancy sensors, and large networks of programmable thermostats. Such operating and control systems afford a high degree of fine-tuning capability and
operating flexibility for differential environmental control in various locations of a building, depending on their exposure to daylight and weather conditions. Other methods include rooftop wind turbines and geothermal heat pumps.

3.2.3 Commercially Viable Options

There are emerging technologies being developed to increase energy efficiency. One such technology is electro chromic windows that can instantly switch from transparent to varying shades of gray in response to a small, applied current. A large view window made with electro chromic materials could be programmed to respond to incoming natural light by stepping down its setting to minimize light transmittance. When integrated with daylight and occupancy sensors and programmable controls, electro chromic windows could be set to automatic and incrementally shade indoor environments in synch with the sun’s arc across the sky.

Computer-simulation programs may impact and improve building energy efficiency. Today’s building energy calculation software is growing in sophistication and could eventually lead to whole-building energy simulation analytical tools that could evaluate low-energy use design factors and optimize incorporation of renewable energy systems.

3.3 BIPV: CONCEPT TO REALITY

Solar photovoltaic technology, applied in residential buildings, is generally used for photovoltaic conversion and lighting. Building integrated photovoltaic (BIPV) is a novel concept for the application of solar power, in brief, fitting the solar photovoltaic unit on the surface of the maintenance structure of the building to provide electricity [6]. Photovoltaic arrays do not take up additional floor space when integrated with the construction, and is the best installation of a photovoltaic generation system, thus attracting much attention. BIPV can be divided into two categories according to the forms that the photovoltaic array is integrated with the buildings [7]. One is the combination of photovoltaic array with building, installing the PV array on the building, and the building plays a supporting role as a photovoltaic carrier (Figure 3.4; [8,9]). The other is the integration of the photovoltaic array with the building. PV modules appear as the building material, and the photovoltaic array becomes the integral part of the construction, such as photoelectric curtain walls, photoelectric tile roof, photoelectric lighting roof, etc. (Figure 3.5; [10,11]).
3.3.1 Building Integration of Photovoltaic Cells

The four main options for building integration of PV cells are on inclined roofs, flat roofs, facades, and shading systems. South-facing inclined roofs are generally best fit for PV installation because of the favorable angle with the sun. One option is to mount PV modules above the roofing system.
Another option is PV modules that replace conventional building materials in parts of the building envelopes, like the roofs or facades, that is, BIPVs. “BIPV is considered a functional part of the building, or they are architecturally incorporated into the building’s design” [12]. The BIPV system serves as building envelope material and a power generator simultaneously [13]. This can provide savings in materials and labor, and also reduce the electricity costs, but obviously increases the importance of water tightness and durability of the BIPV product.

At higher temperature, the performance of the solar cells, especially for mono- and polycrystalline modules decreases. Therefore, an air gap beneath the module is essential to decrease the temperature. The thin-film products, on the other hand, perform more independently of the temperature.

3.3.2 Architectural Aspects of BIPVs

BIPV systems provide many opportunities for innovative architectural design and can be aesthetically appealing. BIPVs can act as shading devices and also form semitransparent elements of fenestration [14]. Amorphous silicon tiles can be used to make a BIPV roof look very much like a standard tiled roof (as shown in Figure 3.5a), while on the other hand semitransparent modules can be used in facades or glass ceilings to create different visual effects (as shown in Figure 3.5b). Some architects enjoy presenting a BIPV roof as a roof giving a clear visual impression, while others want the BIPV roof to look as much like a standard roof as possible. Further information about building integration of solar energy systems in general and architectural integration of PV and BIPV in particular, may be found in the studies by Hestnes [15], Farkas et al. [16], and Peng et al. [12], respectively. The PVs can be integrated in two types as follows.

1. Architectural integration

2. Building integration

Integration of PV into buildings has the following advantages [17]:

- Part of the building is used for PV installation and so additional land is not required. This is particularly significant in densely populated areas in cities.
• The expense of the PV divider or rooftop can be counterbalanced in contrast to the expense of the building component it replaces.

• Power is generated on site and replaces electricity that would otherwise be purchased at commercial rates and avoids distribution losses.

• PV, if grid connected, ensures security of supply and high cost of storage is avoided.

• Architecturally elegant, well-integrated systems will increase market acceptance.

3.3.2.1 Roof Integration of PV

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 part of an impermeable layer in the construction. The other type is that the PV is glued onto insulation material. This kind of warm roof construction arrangement is very well suited to renovating large flat roofs. Using PV modules as roof covering reduces the amount of building materials needed, which is very favorable for a sustainable building and can help to reduce costs. There are also many products for small-scale use, to suit the scale of the roof covering, for example, PV shingles and tiles. The roof integration of PV can be categorized as follows.

• PVs on flat roof
• PVs on inclined/pitched roof
• Roof with integrated PV tiles
• PV in saw-toothed north light roof/sky light
• PVs on curved roof/wall
• PVs in atrium/skylights

For PVs on a flat roof, the PVs are laid horizontally on the flat roofs which are normally not visible from the ground and hence the significance of the aesthetic part of integration can be less. Photovoltaic facilities on inclined or pitched roofs when facing in the right direction are suitable for good energy yield. Architectural aesthetics should be taken into consideration while integrating as these are the visible parts of the building unlike the flat roofs (Figure 3.6a). A roof with integrated PV tiles has been
a normal practice or integrated with larger standard modules of PV on
the roof for energy yield. However, when the integration is to be done on
traditional tiled roofs, it may not always be possible to use large modules
and the character of the roof may also be ruined (Figure 3.6b).

Sawtooth roofs can be implemented as (semi-) transparent or opaque.
Glass sawtooth roofs make optimal use of daylight, protect in contrast to
direct sunlight, and thus reduce a building’s cooling load. The world’s larg-
est integration of thin-film PV systems on the sawtoothed glass roof of Paul

FIGURE 3.6 (CONTINUED) (d) PV integration on the curved roof of BP solar show-
case in Birmingham. (From http://www.solartechnologies.co.uk/) (e) (Left) Atrium
with PV modules, Ludesch/Vlbg., Austria; (right) PV on colored skylights at
Bejar Market, Salamanca, Spain. (From http://www.solarfassade.info/, http://
www.onyxsolar.com/)
Lobe Haus, Berlin optimizes interior light conditions in addition to producing clean energy (Figure 3.6c, left). The flexibility with the integration of PV is further emphasized by the fact that PV modules can also be mounted on curved load-bearing surfaces. Arched surfaces and roofs are equally suited for use with PV systems. This allows added freedom of design involving PV integration. The BP solar showcase in Birmingham, UK is a good example of PV integration of a curved roof (Figure 3.6d). PVs can equally be integrated as multifunctional elements in transparent roof structures or atriums that allow controlled light into the interior. As a semitransparent roof unit, they can protect the building from heat, sunlight, glare, and the weather (Figure 3.6e).

3.3.2.2 Facade Integration of PV
It is a normal building practice that the external walls of buildings are covered with insulation and protective cladding. This covering can be wood, metal sheets, panels, glass, or PV modules. For luxury office buildings, where the cladding is often expensive, integrating PV modules as cladding on opaque parts of the building is not more expensive than other commonly used materials like natural stones, granite, or aluminium cladding. In the Solar XXI building, vertical bands of photovoltaic panels are integrated into the south facade, with an alternative rhythm with the glazing, resulting in an elevation based on the concept of modularity and repetition (Figure 3.7).

![PV integrated into the opaque parts of the façade of Solar XXI building, Portugal. (From http://csc.esbensen.dk.)](image-url)
Façade integration of PV module is installed in two ways on walls depending on inclination.

- PV on inclined walls
- PVs as sunshades

It is quite interesting to incline the façade where PV is integrated basically for two reasons; first because it would then be easy to optimize the PV modules’ position for maximum energy yield and second because this would further add to the elegance of the façade. The west side of the Vocational College in Tirol, Austria is treated in a similar fashion. The PV integrated façade is curved and inclined, which is one of the main features of the architectural expression of the building (Figure 3.8). In energy efficient buildings, south-facing glazing acts as an energy absorber and hence the building can be designed to enable all the solar heat energy to be distributed from the south façade. However, problems can arise in the summer when the building overheats and becomes uncomfortable. High solar heat gain will increase the demand for air conditioning, which will in turn increase the building’s energy requirement. To avoid the energy need for air conditioning, external sunshades could be a good option to prevent

![Inclined PV integrated glazed façade of Vocational College in Tirol, Austria.](http://www.m9-architekten.at/)
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the heat from transmitting into the interior of the building. Typically, sun shades can take the form of a fixed or controlled glass louver system and can be installed either vertically or horizontally on the façade of a building. These shades can be both fixed or movable. Besides, opaque PV modules can equally be used in a similar way as a conventional shading device. The south-glazed PV façade of the Solar-Fabrik building in Freiburg also has integrated PV shades to prevent overheating inside (Figure 3.9).

3.3.3 BIPV Products

There is a wide range of different BIPV products available on the market, which can be categorized in different ways. In this work, the classification is mostly taking into account how the maker depicts the item, and what other sort of material the item is altered to be joined with. The product categories considered are foils, tiles, modules, and solar cell glazing products. Some products hold a variety of properties, therefore making it more difficult to categorize them. This chapter is limited to BIPVs. Nevertheless, there is one more type of PV system classification named building attached photovoltaic (BAPV) products that are not BIPVs, or it is uncertain regarding how the product is mounted. Peng et al. [12] refers to BAPV as an add-on to the building, thus not directly related to the structure’s functional aspects.
3.3.3.1 BIPV Foil Products
Because of light weight and adaptability, foil items are perfect for establishment and the weight constraints most rooftops have. The PV cells are regularly produced using thin-film cells to keep up the adaptability in the foil and the productivity with respect to high temperatures for utilization on nonventilated rooftop arrangements. Unfortunately, there are few manufacturers in the market that offer weather-tight solutions. Table 3.1 presents an example of a foil product, displaying the open circuit potential/voltage $U_{OC}$, short circuit current $I_{SC}$, maximum power point $P_{\text{max}}$, and the fill factor $FF$.

3.3.3.2 BIPV Tile Products
The BIPV tile products can cover the entire roof or just parts of the roof. They are normally arranged in modules with the appearance and properties of standard roof tiles and substitute a certain number of tiles. This is a good option for retrofitting of roofs. The cell type and tile shape vary. Some tile products look like curved ceramic tiles (see Figure 3.5a) and will not be area effective owing to the curved surface area, but may be more aesthetically attractive. Table 3.2 gives examples of four photovoltaic tile products that are on the market today.

3.3.3.3 BIPV Module Products
The BIPV module products presented are slightly similar to conventional PV modules. The dissimilarity, however, is that they are prepared with weather skin solutions. Some of the products can replace dissimilar kinds of roofing, or they are suitable for a particular roof application produced by its manufacturer, for example, Rheinzink’s “Solar PV Click Roll Cap System” [18]. These mounting systems raise the simplicity of installation. There is a huge amount of products on the market and some of them are promoted as BIPV products without functioning as weather skin. Other products are not specific on how they are installed, which leads to uncertainty whether they are BIPVs or BAPVs. Some of the products in this type are premade modules with isolation or other elements incorporated in the body. Table 3.3 gives examples of BIPV module products.

3.3.3.4 Solar Cell Glazing Products
Solar cell glazing products give an awesome assortment of alternatives for windows, glassed or tiled exteriors, and rooftops. Distinctive hues and transparencies can make various tastefully satisfying results conceivable.
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TABLE 3.1  Literature Data for One of the BIPV Foil Products

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product*</th>
<th>η (%)</th>
<th>U$_{oc}$ (V)</th>
<th>I$_{sc}$ (A)</th>
<th>P$_{max}$ (W)</th>
<th>FF</th>
<th>Area (mm × mm)</th>
<th>P$_{max}$/Area (W/m$^2$)</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alwitra GmbH &amp; Co.</td>
<td>Evalon V Solar 408</td>
<td>138.6</td>
<td>5.1</td>
<td>408/module</td>
<td>0.58</td>
<td></td>
<td>1550 × 6000</td>
<td>42.9</td>
<td>Amorphous silicon cells</td>
</tr>
<tr>
<td>Alwitra GmbH &amp; Co.</td>
<td>Evalon V Solar 136</td>
<td>46.2</td>
<td>5.1</td>
<td>136/module</td>
<td>0.58</td>
<td></td>
<td>1050 × 3360</td>
<td>38.5</td>
<td>Amorphous silicon cells</td>
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</tbody>
</table>

* Several models are available from the producer in the Evalon V Solar series.
## TABLE 3.2 Literature Data for Some of the BIPV Tile Products

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Producta</th>
<th>η (%)</th>
<th>U_{oc} (V)</th>
<th>I_{sc} (A)</th>
<th>P_{max} (W)</th>
<th>FF</th>
<th>Area (mm × mm)</th>
<th>P_{max}/Area (W/m²)</th>
<th>Material</th>
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</thead>
<tbody>
<tr>
<td>Solar-dachstein</td>
<td>STEP-design</td>
<td>23.15</td>
<td>2.4</td>
<td>1.36/cell</td>
<td>0.76</td>
<td>8 units 100 × 100</td>
<td>136</td>
<td>Poly-crystalline silicon cells</td>
<td></td>
</tr>
<tr>
<td>SRS Energy</td>
<td>Solé Powertile</td>
<td>6.3</td>
<td>4.6</td>
<td>15.75/module</td>
<td>0.54</td>
<td>868 × 457.2</td>
<td>39.7</td>
<td>Amorphous silicon cells from Uni-Solar</td>
<td></td>
</tr>
<tr>
<td>Lumeta</td>
<td>Solar Flat Tile</td>
<td>7.4</td>
<td>5.2</td>
<td>28/module</td>
<td>0.73</td>
<td>432 × 905</td>
<td>71.6</td>
<td>Mono-crystalline silicon cells</td>
<td></td>
</tr>
<tr>
<td>Solar Century</td>
<td>C21e Tile</td>
<td>20/cell</td>
<td>12</td>
<td>5.55</td>
<td>52/module</td>
<td>0.78</td>
<td>1220 × 420</td>
<td>101.5</td>
<td>Mono-crystalline cells</td>
</tr>
</tbody>
</table>

* Several models are available from the producer.
<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product*</th>
<th>η (%)</th>
<th>$U_{OC}$ (V)</th>
<th>$I_{SC}$ (A)</th>
<th>$P_{max}$ (W)</th>
<th>FF</th>
<th>Area (mm × mm)</th>
<th>$P_{max}$/Area (W/m²)</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creaton AG</td>
<td>Creaton Solesia</td>
<td>13.86</td>
<td>8.46</td>
<td>90/module</td>
<td>0.77</td>
<td></td>
<td>1778 × 355</td>
<td>142.6</td>
<td>Mono-crystalline silicon cells</td>
</tr>
<tr>
<td>Rheinzink</td>
<td>PV Quickstep</td>
<td>17.1</td>
<td>5.12</td>
<td>68/module</td>
<td>0.78</td>
<td></td>
<td>2000 × 365</td>
<td>93.2</td>
<td>Crystalline silicon cells</td>
</tr>
<tr>
<td>Abakus Solar AG</td>
<td>Peak On P220-60</td>
<td>13.2</td>
<td>36.77</td>
<td>8.22</td>
<td>220</td>
<td>0.73</td>
<td>1667 × 1000</td>
<td>132</td>
<td>Poly-crystalline silicon cells</td>
</tr>
<tr>
<td></td>
<td>Peak On P235-60</td>
<td>14.6</td>
<td>37.21</td>
<td>8.48</td>
<td>235</td>
<td>0.74</td>
<td>1630 × 1000</td>
<td>144.2</td>
<td>Poly-crystalline silicon cells</td>
</tr>
<tr>
<td></td>
<td>ANT P6-60-230</td>
<td>14.07</td>
<td>36.77</td>
<td>8.42</td>
<td>230</td>
<td>0.74</td>
<td>1658 × 986</td>
<td>140.7</td>
<td>Poly-crystalline silicon cells</td>
</tr>
<tr>
<td>Dubont</td>
<td>Gevity</td>
<td>17.7</td>
<td>24.20–24.43</td>
<td>8.77–8.87</td>
<td>160–165</td>
<td>0.75–0.76</td>
<td>1332.5 × 929</td>
<td>129.36–133.4</td>
<td>Mono-crystalline silicon cells</td>
</tr>
<tr>
<td>Suntech</td>
<td>MSZ-190J-D</td>
<td>45.2</td>
<td>5.62</td>
<td>190/module</td>
<td>0.75</td>
<td></td>
<td>1641 × 834.5</td>
<td>139</td>
<td>Mono-crystalline silicon cells</td>
</tr>
<tr>
<td></td>
<td>MSZ-90J-CH</td>
<td>22.4</td>
<td>5.29</td>
<td>90/module</td>
<td>0.76</td>
<td></td>
<td>879 × 843.5</td>
<td>125</td>
<td>Mono-crystalline silicon cells</td>
</tr>
<tr>
<td>Schott Solar</td>
<td>InDax 214</td>
<td>12.5</td>
<td>36.3</td>
<td>8.04</td>
<td></td>
<td></td>
<td>1769 × 999</td>
<td></td>
<td>Poly-crystalline silicon cells</td>
</tr>
<tr>
<td></td>
<td>InDax 225</td>
<td>13.1</td>
<td>33.5</td>
<td>6.6</td>
<td></td>
<td></td>
<td>1769 × 999</td>
<td></td>
<td>Poly-crystalline silicon cells</td>
</tr>
<tr>
<td>Solar Century</td>
<td>C21e Slate</td>
<td>20/</td>
<td>5.55</td>
<td>52</td>
<td>0.78</td>
<td></td>
<td>1174 × 318</td>
<td>139.3</td>
<td>Mono-crystalline silicon cells</td>
</tr>
</tbody>
</table>

* Several models are available from the producer.
TABLE 3.4 Literature Data For Some Solar Cell Glazing Products

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product</th>
<th>η (%)</th>
<th>U_{oc} (V)</th>
<th>I_{sc} (A)</th>
<th>P_{max} (W)</th>
<th>FF</th>
<th>Area (mm × mm)</th>
<th>P_{max}/Area (W/m²)</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abakus Solar AG</td>
<td>Peak In P210–60</td>
<td>36.5</td>
<td>7.7</td>
<td></td>
<td></td>
<td></td>
<td>2000 × 1066</td>
<td></td>
<td>Poly-crystalline silicon cells</td>
</tr>
<tr>
<td>Vidursolar</td>
<td>FV VS16 C36 P120</td>
<td>21.6</td>
<td>7.63</td>
<td></td>
<td></td>
<td></td>
<td>1600 × 720</td>
<td></td>
<td>Poly-crystalline silicon cells</td>
</tr>
<tr>
<td>Glaswerke Arnold GmbH &amp; Co KG</td>
<td>Voltarlux-ASI-T-Mono 4-fach</td>
<td>93</td>
<td>1.97</td>
<td></td>
<td>100/module</td>
<td>0.55</td>
<td>2358 × 1027</td>
<td>41.3</td>
<td>Amorphous silicon cells from Schott Solar</td>
</tr>
<tr>
<td>Schott Solar</td>
<td>ASI THRU-1-L</td>
<td>6</td>
<td>111</td>
<td>0.55</td>
<td>48</td>
<td>0.79</td>
<td>1122 × 690</td>
<td>62</td>
<td>Amorphous silicon cells</td>
</tr>
<tr>
<td></td>
<td>ASI THRU-4-IO</td>
<td>6</td>
<td>111</td>
<td>2.22</td>
<td>190</td>
<td>0.77</td>
<td>1122 × 2619</td>
<td>64.7</td>
<td>Amorphous silicon cells</td>
</tr>
<tr>
<td>Sapa Building System</td>
<td>Amorphous silicon thin film</td>
<td>5/cell</td>
<td></td>
<td></td>
<td>32/cell</td>
<td></td>
<td>576 × 976/cell</td>
<td>50</td>
<td>Amorphous silicon thin film</td>
</tr>
<tr>
<td></td>
<td>Poly-crystalline</td>
<td>16/cell</td>
<td></td>
<td></td>
<td>1.46–3.85/cell</td>
<td></td>
<td>156 × 156/cell</td>
<td>120</td>
<td>Poly-crystalline</td>
</tr>
<tr>
<td></td>
<td>Mono-crystalline high efficient</td>
<td>22/cell</td>
<td></td>
<td></td>
<td>2.90–3.11/cell</td>
<td></td>
<td>125 × 125/cell</td>
<td>155</td>
<td>Mono-crystalline high efficient</td>
</tr>
</tbody>
</table>

* Several models are available from the producer.
The modules transmit daylight and function as water and sun shield. “The technology involves spraying a coating of silicon nanoparticles onto the window, which work as solar cells” [19]. The separation between the cells relies on needed transparency level and the criteria for power creation; however, ordinarily the separation is somewhere around 3 and 50 mm. The space in between cells transmits diffuse daylight. Along these lines, both shading and normal lighting is given while creating power. The producers of sunlight-based cell glazing items generally offer recyclable items for the particular project, while Table 3.4 shows some predefined modules. The producers also offer customized modules regarding shape, cell material, color, and transparency level, that is, the distance between cells. Values for the efficiencies are not given for these products, but for Voltarlux an FF value of 0.55 is given with a transparency level of 10%. The transparency level varies from 16% to 41%, respectively, for smallest to largest size, for the Vidursolar models, and is 25% for Abakus’ Peak In P210-60.

3.4 MAJOR DEVELOPMENTS

There is a huge potential for the BIPV market all over the world. However, there is an established market in a number of the countries in Europe, that is, Spain, Germany, France, Switzerland, and Italy. Many governments in these countries are sponsoring the BIPV technology by implementing a Feed in Tariff (FiT) system. This concept allows selling back excessive power to the grid at a higher price than the grid price of the electricity. The worldwide growth rate of BIPV during the last seven years is approximately 50% of installed capacity in every year. There is more than 1300 MW of installation to date. The upcoming BIPV market growth is shown in Figure 3.10 to the year 2020 [20]. BIPV installation in 2020 is expected to grow with a growth rate of 30% in each year. The expected installation is more than 8000 MW by end of year 2020. Table 3.5 presents the overall business of PV modules by different companies. It is observed that there is no leading PV module manufacturer in the world. Moreover, manufacturers like Sun Tech occupy only 9.2% of the PV market Table 3.6 [21,22].

Figure 3.11 shows the current BIPV installed systems in the world and some prediction for its future expansion [23]. Figure 3.12 shows the development status of different countries in the BIPV market. In Europe, based on the information on the European Photovoltaic Industry Association in the year 2012 [24], Germany misplaced the top growing market in Italy in 2011; this country is still the biggest PV market in the world. In the year 2011, Germany added 7.5 MW to its previous installation while Italy
did almost 9.3 MW and experienced an astonishing growth at the time. The FiT plays a significant role in this achievement (€5.5 billion per year). About half of the PV installations in the world are installed in these two countries. France is the third European country that managed to add more than 1 GW to its market.

![BIPV market: global installation capacity forecasted till 2020 in MW. (From Frost and Sullivan. European building integrated photovoltaic market. Report. 2008.)](image)

**TABLE 3.5** The Competitive Structure of the BIPV Market (Solar Buzz)

<table>
<thead>
<tr>
<th>PV Module Manufacturer</th>
<th>Country</th>
<th>% of Market Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suntech</td>
<td>China</td>
<td>9.2</td>
</tr>
<tr>
<td>Yingli Green Energy Energy</td>
<td>China</td>
<td>7.6</td>
</tr>
<tr>
<td>Canadian Solar</td>
<td>Canada</td>
<td>7.6</td>
</tr>
<tr>
<td>Trina Solar</td>
<td>China</td>
<td>6.9</td>
</tr>
<tr>
<td>Sharp Solar</td>
<td>Japan</td>
<td>6</td>
</tr>
<tr>
<td>Solar fun</td>
<td>China</td>
<td>5.4</td>
</tr>
<tr>
<td>First Solar</td>
<td>US</td>
<td>5.3</td>
</tr>
<tr>
<td>Jabil Circuit</td>
<td>US</td>
<td>4.2</td>
</tr>
<tr>
<td>Solar World</td>
<td>US</td>
<td>4.1</td>
</tr>
<tr>
<td>Sun Power</td>
<td>US</td>
<td>3.6</td>
</tr>
<tr>
<td>LDK</td>
<td>China</td>
<td>3.4</td>
</tr>
<tr>
<td>Sanyo Electric</td>
<td>US</td>
<td>3.3</td>
</tr>
<tr>
<td>REC</td>
<td>Norway</td>
<td>3</td>
</tr>
<tr>
<td>Kyocera</td>
<td>Japan</td>
<td>3</td>
</tr>
<tr>
<td>JA Solar</td>
<td>China</td>
<td>2.8</td>
</tr>
<tr>
<td>Jinko Solar</td>
<td>China</td>
<td>2.6</td>
</tr>
<tr>
<td>Ningbo Solar Electric</td>
<td>China</td>
<td>2.5</td>
</tr>
<tr>
<td>Renesola</td>
<td>China</td>
<td>2.1</td>
</tr>
<tr>
<td>Others</td>
<td></td>
<td>17.4</td>
</tr>
</tbody>
</table>
TABLE 3.6
List of Major BIPV Projects with Different Photovoltaic Categories

<table>
<thead>
<tr>
<th>PV Categories</th>
<th>Project Name</th>
<th>Project Location</th>
<th>Latitude/Longitude</th>
<th>Year of Establishment</th>
<th>Capacity of the Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof-top integration</td>
<td>Black River Park commercial Roof Top Solar Project</td>
<td>Cape Town, South Africa</td>
<td>35° 55’ S 18° 22’ E</td>
<td>2014</td>
<td>1.2 MWp</td>
</tr>
<tr>
<td>Roof-top integration</td>
<td>Solar PV plant, Punjab</td>
<td>Amritsar, Punjab, India</td>
<td>31° 37’ N 74° 55’ E</td>
<td>2014</td>
<td>7.52 MWp</td>
</tr>
<tr>
<td>Roof-top integration</td>
<td>Centro Ingrosso Sviluppo companno in Nola</td>
<td>Nola-Naples, Italy</td>
<td>40° 55’ 33.96” N 14° 31’ 38.64” E</td>
<td>2013</td>
<td>20.252 MWp</td>
</tr>
<tr>
<td>Roof-top integration</td>
<td>Riverside Renewable Energy-Holt logistics Refrigerated warehouse</td>
<td>Gloucester City, New Jersey</td>
<td>39° 53’ 29.67” N 75° 7’ 0.12” W</td>
<td>2012</td>
<td>9 MWp</td>
</tr>
<tr>
<td>Roof-top integration</td>
<td>Avidan Energy Solution</td>
<td>Edison, New Jersey</td>
<td>40° 30’ 14.4” N 74° 20’ 57.84” W</td>
<td>2011</td>
<td>4.26 MWp</td>
</tr>
<tr>
<td>Roof-top integration</td>
<td>Goodyear Dunlop logistic center</td>
<td>Philipps burg, Germany</td>
<td>49° 13’ 59.88” N 8° 27’ E</td>
<td>2011</td>
<td>7.4 MWp</td>
</tr>
<tr>
<td>Roof-top integration</td>
<td>Toys “R” Us distribution center</td>
<td>Flanders, New Jersey</td>
<td>40° 50’ 52” N 74° 42’ 34” W</td>
<td>2011</td>
<td>5.38 MWp</td>
</tr>
<tr>
<td>Roof-top integration</td>
<td>Boeing 787 assembly building, South Carolina</td>
<td>North Charleston South Carolina</td>
<td>32° 58’ 28.52” N 80° 4’ 8.99” W</td>
<td>2011</td>
<td>2.6 MWp</td>
</tr>
<tr>
<td>Roof-top integration</td>
<td>Shanghai No. 1/2 Metro operation Co. Ltd.</td>
<td>Hongqiao Railway Station, Shanghai, China</td>
<td>31° 12’ N 121° 30’ E</td>
<td>2010</td>
<td>6.68 MWp</td>
</tr>
<tr>
<td>Roof-top integration</td>
<td>FedEx</td>
<td>Wood bridge, New Jersey</td>
<td>40° 33’ 38.88” N 74° 17’ 33.36” W</td>
<td>2010</td>
<td>2.42 MWp</td>
</tr>
<tr>
<td>Roof-top integration</td>
<td>GSA Bean Federal Centre</td>
<td>Indianapolis, Indiana</td>
<td>39° 47’ 27.6” N 86° 8’ 52.8” W</td>
<td>2010</td>
<td>2.012 MWp</td>
</tr>
</tbody>
</table>

BIPV product improvement has been continuing for the past 30 years, but its practical applications have been slow in contrast to conventional rack-mounted solar PV. Although we can see the substantial rise of tendency toward solar systems all over the world, several problems have to be solved if we want to keep this trend. In this chapter, we have classified the barriers into four main groups as shown in Figure 3.13.

**Figure 3.11** Global BIPV installation and prediction of its expansion rate. (From Battery, S. BIPV Technology and Market Forecast, 2011.)

**Figure 3.12** Development status of different countries in BIPV market and their future progress. (From Battery, S. BIPV Technology and Market Forecast, 2011.)

### 3.5 BARRIERS AND FUTURE DIRECTIONS

BIPV product improvement has been continuing for the past 30 years, but its practical applications have been slow in contrast to conventional rack-mounted solar PV. Although we can see the substantial rise of tendency toward solar systems all over the world, several problems have to be solved if we want to keep this trend. In this chapter, we have classified the barriers into four main groups as shown in Figure 3.13.
Institutional barriers can be overcome by making strong permanent supportive policies and plans, governments can empower these programs. Sometimes these plans can entirely revolutionize the situations and open up new channels. For instance, Spain’s encouragement of renewable energies was confirmed in 1999 but the big evolution did not happen until 2005 when the promotion of renewable energy (PER) was planned. Consequently, after Germany, Spain holds the second position in the EU ranking in the year 2009. Success or failure in BIPV projects completely depends on citizens’ cooperation. Having people educated about the importance of consuming renewable energy and the risks of using fossil fuels such as oil and coal imposed on us and our planet are critical. In view of the low productivity of panels and the amount of energy that we can produce by them is not huge, these projects require more opportunity to end up prominent. So civilians have to be patient and administrations should devote sufficient time and funds to upsurge their knowledge and provoke novel ideas. Rules and regulations should also be simplified enough to become more understandable to the public. Economics is the foremost barrier that obstructs our goals. Without government collaborations, projects will certainly fail. The important impact of strong policy making and enough economic incentives and supports such as loans with low interests and long-term durability, grants and reduced taxes for conducting progressive BIPV projects are stated in various studies. Investing in BIPV systems is a long-term investment and its best result will be revealed 20 years later. Thus, convincing companies and people to work with this investment depends on the government’s power and concerns.

One of the main reasons for limited markets and practical applications is that the technical barriers, which span from design phase through to commissioning and maintenance phases, have not been understood by shareholders. All of these barriers can not necessarily be removed by a single solitary branch of knowledge, but rather it needs interdisciplinary...
efforts. The technical barriers of BIPV at different stages are given in Figure 3.14.

FIGURE 3.14 Technical barriers of BIPV at different stages.

3.5.1 Future Direction

3.5.1.1 New Materials and Solutions for BIPVs

The future research opportunities are in view of the current products. Huge numbers of items can accomplish a higher proficiency with better materials and better solutions. Actually, advances in the improvement of PV materials will prompt advances for the BIPV frameworks. The challenge is accomplishing this at a suitable expense.

New PV technologies that may start and progress new developments, which may be developed into BIPV, may be found in different fields, for
example, (a) ultra-low cost, low-medium efficiency, organic based modules, (b) ultra-high efficiency modules, (c) solar concentrator and/or solar trapping systems embedded in the solar cell surface and material beneath, and (d) flexible lightweight inorganic thin film solar cells, or others. The development of new PV materials and technologies in the future will contribute to new and improved BIPV products, for example, with higher solar efficiencies.

The new solutions in the PV industry are many and various. There is usually room for improvement in each specific system, for example, regarding ventilation rate, positioning, removing of snow, etc. For good integration results, the BIPV system has to be included early in the planning process. Communication between the planners and manufacturers of BIPV products is important for the development of new BIPV solutions. If the PV cells used are mono- or polycrystalline, it is very important to achieve a sufficient ventilation rate, as the solar cell efficiency normally decreases with increasing temperature, and should therefore be planned ahead of the construction phase. If the temperatures reach high levels, one might have to install compensating solutions, such as fans, etc., although this is usually not optimal regarding maintenance and energy efficiency. The BIPV might be formed as a trough at a material level and hence lead to improved efficiency and reduced costs of the building integrated PV cells. Figure 3.15 [25] shows research cell efficiency records of NREL up to 2015.

3.5.1.2 Long-Term Durability of New Materials and Solutions
It is imperative that the new building materials, integrated technology, and solutions are arranged all the while with the building covering. This incorporates prerequisites for rainfall, wind and air tightness, building physical contemplations, and long-term durability with respect to atmospheric exposure. Building physical considerations include investigation of the moisture transport and with this the condensation risk. With new materials the moisture transport and distribution within the building element might change and knowledge about these aspects is important. The long-term durability versus the numerous climate exposure issues needs to be deliberated. Examples of this are as follows [26]:

- Solar radiation (UV–VIS–NIR)
- Ambient infrared (IR) heat radiation
- High and low temperatures
Best research-cell efficiencies

- **Multijunction cells (2-terminal, monolithic)**
  - LM = lattice matched
  - MM = metamorphic
  - IMM = inverted, metamorphic
- **Three-junction (concentrator)**
- **Two-junction (concentrator)**
- **Two-junction (non-concentrator)**
- **Four-junction or more (concentrator)**
- **Four-junction or more (non-concentrator)**

**Single-junction GaAs**
- Concentrator
- Thin-film crystal
- Crystalline Si cells
- Single-crystal (concentrator)
- Single-crystal (non-concentrator)
- Multicrystalline
- Silicon heterojunction (HIT)
- Thin-film crystal

**Thin-film technologies**
- CIGS (concentrator)
- CIGS (MM, 302x)
- Amonorphous Si (stabilized)
- Organic cells (various types)
- Inorganic cells (CZTS, Se)
- Quantum dot cells

**Emerging PV**
- Dye-sensitized cells
- Perovskite cells (not stabilized)
- Quantum dot cells

**Other technologies**
- Single-junction GaAs
- Two-junction GaAs
- Four-junction or more (concentrator)
- Four-junction or more (non-concentrator)
- Three-junction (concentrator)
- Three-junction (non-concentrator)
- Organic tandem cells
- Organic cells (various types)
- Quantum dot cells

**Organic cells (various types)**
- Single-junction GaAs
- Two-junction GaAs
- Four-junction or more (concentrator)
- Four-junction or more (non-concentrator)
- Three-junction (concentrator)
- Three-junction (non-concentrator)
- Organic tandem cells
- Organic cells (various types)
- Quantum dot cells

**Other technologies**
- Single-junction GaAs
- Two-junction GaAs
- Four-junction or more (concentrator)
- Four-junction or more (non-concentrator)
- Three-junction (concentrator)
- Three-junction (non-concentrator)
- Organic tandem cells
- Organic cells (various types)
- Quantum dot cells

**Research cell efficiency records.** (From http://www.nrel.gov/ncpv/images/efficiency_chart.jpg.)
• Temperature changes/cycles giving freezing/thawing processes
• Water, for example, moisture and wind-driven rain
• Physical strains, for example, snow loads
• Wind
• Erosion, also from the above factors
• Pollutions, for example, gases and particles in air
• Microorganisms
• Oxygen
• Time for all the factors above to work

The main aims of BIPV is replacing conventional roof and facade materials with photovoltaic materials, which act as a covering materials as well as generating electricity.

3.6 SUMMARY AND CONCLUSIONS

BIPV is a standout among the most encouraging and exquisite methods for creating on location power straightforward from the sun—quietly, without environmental harm, pollution, or exhaustion of assets. With BIPV innovation, solar energy collection is integrated into the building envelope as a major aspect of the outline. The PV modules fill a double need: they replace building envelope materials and they produce power. While this innovation has been consolidated into the outline of numerous new structures, it is still a rising practice in the world. The introductory expense of BIPV is balanced by decreasing the sum spent on ordinary building materials and labor that would typically be utilized to develop that part of the building. When the building is in operation, there are extra investment funds as the daylight produces electrical vitality. These favorable circumstances make BIPV one of the quickest developing parts of the photovoltaic business.

There are numerous parts of the building that can be effortlessly substituted with photovoltaics: spandrel glass, bay skylights, rooftops, windows, and exteriors. In these applications, BIPV is a part of the structure and the look of a building, not an add-on. New advances are a work in progress and will later on give BIPVs higher efficiencies and lower generation costs. This will enhance the economic viability and prudent payback time for
BIPV installation. A percentage of the new ideas are organic-based PVs, for example, dye sensitized TiO₂ cells, and high proficiency modules. New arrangements can likewise both decrease expenses and increase the market share among others in the retrofitting business. The solutions ought to be effectively pertinent, and a case of future visions is paint utilizations of PV cells. Every single new technology and solution ought to be altogether tried and endorsed as per existing principles. Moreover, with new items there is a requirement for advancement of new measures and techniques, for example, concerning term strength versus atmosphere presentation.

REFERENCES
